U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-274 565

Alternatives for Hazardous Waste Management in the Inorganic Chemicals Industry

Versar, Inc, Springfield, Va

Prepared for

Environmental Protection Agency, Washington, D C Office of Solid Waste Management Programs

3 Jun 77

PB 274 565

ALTERNATIVES FOR HAZARDOUS WASTE MANAGEMENT IN THE INORGANIC CHEMICALS INDUSTRY

This final report (SW-149c) describes work performed
for the Federal solid waste management program
under contract no. 68-01-4190
and is reproduced as received from the contractor

U.S. ENVIRONMENTAL PROTECTION AGENCY

1977

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.

4. Title and Subtitle
Alternatives for Hazardous Waste Management in the Inorganic Chemicals Industry

5. Report Date
June 3, 1977

6.

7. Author(s)
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8. Performing Organization Rept. No. 494

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10. Project/Task/Work Unit No.

11. Contract/Grant No.
EPA 68-01-4190

12. Sponsoring Organization Name and Address
Environmental Protection Agency
Office of Solid Waste
Hazardous Waste Management Division (AW-465)
Washington, D.C. 20460

13. Type of Report & Period Covered
Final
Sept. 1976 thru Jan.1977

14.

15. Supplementary Notes
EPA Project Officer - Alexandra G. Tarnay

16. Abstracts

The overall objective of this study was to assess the alternatives to land disposal for treatment and disposal of potentially hazardous wastes generated by the inorganic chemicals industry.

The aim of this project was to identify promising resource recovery and detoxification oriented treatment techniques which are applicable to these wastes.

This study provides:

a) Information on feasible alternatives to current inadequate disposal methods.
b) Data needed by industry in its effort to deal with increasing volumes of hazardous solid waste.
c) Information on R&D needs for treatment processes showing high potential for improved waste management.

The technical effort was accomplished in three main tasks: Information gathering, consultation and process selection; Information analysis, costing and reporting; Comparison Studies

17. Key Words and Document Analysis. 17a. Descriptors

Resource Recovery
Detoxification
Waste Volume Reduction
Disposal Costs
Sanitary Landfill
Chemical Landfill
Waste Treatments
Treatment Costs
Cost Comparisons

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21.
	20. Security Class (This Page) UNCLASSIFIED	22. Price A14- A01

FORM NTIS-35 (REV. 10-73) ENDORSED BY ANSI AND UNESCO. THIS FORM MAY BE REPRODUCED USCOMM-DC 8265-P74

This report as submitted by the grantee or contractor has been technically reviewed by the U.S. Environmental Protection Agency (EPA). Publication does not signify that the contents necessarily reflect the views and policies of EPA, nor does mention of commercial products constitute endorsement by the U.S. Government.

An environmental protection publication (SW-149c) in the solid waste management series.

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1.0 INTRODUCTION

1.1 Project Scope

This report is the result of a study commissioned by the U.S. Environmental Protection Agency (EPA) to assess the alternatives to land disposal for the treatment/disposal of industrial wastes generated by the inorganic chemicals industry and which have been identified as "potentially hazardous" in an earlier EPA study conducted under Contract No. 68-01-2246.

This study, referred to as "The Alternatives Study", identifies technically feasible treatment techniques for potentially hazardous wastes. These treatment techniques accomplish resource recovery, waste detoxification or reduce the volume of waste for ultimate disposal. According to the priority developed by EPA, resource recovery techniques are preferred to detoxification or destruction methods, which in turn are preferred over land disposal.

Versar, Inc., General Technologies Division, began this project for the EPA's Office of Solid Waste (OSW) on September 1, 1976. This report contains the essential elements of the technical information in five major sections. The results are summarized in the Executive Summary, Section 2.0.

Section 3.0 - Major Solid Waste Problem Areas in Inorganic Chemicals Industry

Identifies the potentially hazardous waste streams under study and characterizes the industries which generate these wastes with regard to the number, location, size and their production capacity.

Section 4.0 - General Description of Technologies Appropriate for Treating Inorganic Wastes

Discusses technologies applicable for treating inorganic waste streams.

Section 5.0 - Treatment Processes Selected for a Given Waste Stream

Identifies, describes, analyzes and costs the processes selected for the treatment of a given waste stream.

Section 6.0 - Land Disposal of Wastes

Defines land disposal options and estimates the cost of implementation of plant operated individual sanitary and chemical landfills for each waste stream.

Section 7.0 - Comparison Studies

Compares the cost of the proposed treatment process to sanitary and chemical land disposal for each waste stream.

The individual elements of each of these phases are presented in detail in their respective sections of this report.

1.2 Project Objective

The objective of this project is to identify and cost promising resource recovery and detoxification oriented treatment techniques which are applicable to the potentially hazardous wastes generated by the inorganic chemicals industry. The purposes of this investigation are threefold:

(1) To provide information on technically feasible alternatives to current inadequate disposal methods. These alternatives may be needed if current practices are to be restricted by legislation.

(2) To assemble data needed by industry in its effort to deal with increasing volumes of potentially hazardous solid wastes.

(3) To identify research and development needs for selected treatment processes showing a potential for improved waste management.

1.3 Project Background

This study is a follow-on to two prior studies sponsored by the Office of Solid Waste. These are:

(1) "Assessment of Industrial Hazardous Waste Practice, Inorganic Chemicals Industry" conducted under EPA Contract 68-01-2246. This study characterized the industries, identified the types, quantities, and sources of potentially hazardous wastes generated by the industry and assessed the current disposal/treatment technologies utilized by the industry. Certain wastes were classified as being potentially hazardous. No final judgments were passed as to this classification. It was recognized and understood that additional information would be required regarding the actual fate of such materials in a given "disposal" environment. An in-depth analysis of this industry revealed that most of these wastes are land disposed in poorly designed facilities and are being handled in an environmentally unacceptable manner.

(2) "Application of Physical, Chemical and Biological Treatment Techniques to Hazardous Waste Management" conducted under EPA Contract 68-01-2288. Using literature searches, plant visits and personal interviews, the "Treatment Study" provided a comprehensive, in-depth, state-of-the-art study of 43 chemical, physical and biological unit processes that could treat potentially hazardous wastes. While the "Treatment Study" offers a useful orientation regarding the general potential utility of the various unit processes for the design and implementation of resource recovery, detoxification and volume reduction systems, it is not aimed to provide detailed designs of such systems for specific waste streams; rather, it is aimed to provide background information that would aid subsequent "Alternative Study" contractors in selecting relevant treatment processes for specific waste streams.

These two previous efforts form the backbone of the "Alternatives Study". This study focuses on (a) the nineteen waste streams identified as potentially hazardous in EPA Contract 68-01-2246 and (b) the 43 physical, chemical and biological treatment techniques identified in EPA Contract 68-01-2288 as having potential utility for waste treatment. According to EPA's directive, any treatment technology which was not covered by the "Treatment Study" was to be considered outside of the scope of work in this study.

1.4 Project Methodology

The conduct of the project can be described in terms of the following work phases:

(1) data acquisition,

(2) develop data basis for the physical form of the waste streams, waste quantities and chemical composition,

(3) select treatment processes for each waste stream,

(4) process information analysis,

(5) cost analysis of selected treatment processes,

(6) cost analysis of land disposal,

(7) cost comparison.

1.4.1 Data Acquisition

The data needed for this study were obtained by five different methods. The first was by reviewing published information in the technical literature and government documents made available by OSW. These references are cited throughout this report and listed in Section 8.0.

The second method involved the utilization of in-house data compiled during the previous work on assessment of industrial hazardous waste practices and effluent limitations guidelines studies on the inorganic chemicals industry for the EPA.

A third method involved trade association participation. The Chlorine Institute in New York City and the Manufacturing Chemists Association in Washington, D.C., were contacted for assistance.

The fourth method of data acquisition was by contacting various plants and knowledgeable personnel of inorganic chemical manufacturing establishments to generate missing data on waste streams and obtain detailed process information on several full scale, operational resource recovery processes. Names of individuals contacted are also cited in this report.

The fifth method was to utilize the consultation services of the "Treatment Study" contractor, provided by EPA, to transfer expeditiously the expertise gained on various unit operations relative to this study.

1.4.2 Develop Data Base

At the onset of the project, it was recognized that a well organized data base on the subject of potentially hazardous waste streams was essential to formulate meaningful conclusions regarding opportunities for resource recovery, detoxification and volume reduction. Therefore, an initial objective of the project was taken to be the assembly of a base set of solid waste characterization information. Emphasis was placed upon the review of in-house information and collection and assessment of missing data to bridge the gaps. Accordingly, the industry and several trade and professional organizations were contacted and the necessary data assembled and compiled. The waste streams under consideration were then characterized in terms of their physical form, chemical composition and were quantified in terms of metric tons per day of each identified waste component based on a typical plant size of the manufacturing establishment which generates these wastes during the course of their production.

1.4.3 Treatment Process Selection

After waste stream characterization, an intensive effort was directed toward a detailed literature search and reviewing and analyzing information presented in the document entitled "Analysis of Potential Application of Physical, Chemical and Biological Treatment Techniques to Hazardous Waste Management". The first criterion used in process selection was to eliminate inappropriate processes from consideration at the earliest stage possible. Most of the 43 processes identified in the "Treatment Study" as treatment processes are unit operations, several of which would normally have to be combined in series to form a complete treatment system for a given waste stream. Twenty of these processes were found to have no potential application to inorganic chemical industry wastes. This left 23 as potentially useful processes to be investigated. Subsequently, wastes were matched with treatment processes. Factors considered essential and used in comparing attractive individual processes were:

(1) the physical form of the waste stream and the feed requirement of the individual unit processes,

(2) the potential of individual applicable processes for material recovery, energy recovery, detoxification or immobilization,

(3) the expected environmental impact from each suitable unit process,

(4) the developmental state of the applicable unit processes,

(5) the technical feasibility of the applicable processes without consideration of economic aspects.

For each waste stream, characterized by its physical form and hazardous components, the matrix criteria presented in Section 4.0 were used to select potentially applicable treatment processes. This matrix also provided guidance for eliminating processes that were inapplicable to a given waste stream. Because of the treatment priority order defined by OSW, the first attempt was to look for those processes which would either lead directly to a reusable resource or would convert the waste to a form from which resources might be more easily recovered. Detoxification and volume reduction were considered only if the waste stream did not lend itself to resource recovery.

Based on in-house expertise and upon information provided by the "Treatment Study" document, an attempt was made to identify several innovative resource recovery or detoxification possibilities for each waste stream. These treatment possibilities were then discussed and reviewed with the pertinent "Treatment Study" contractor staff members during joint sessions at their offices. The processes identified as having the best potential to treat each of the wastes were submitted to EPA for review and approval.

1.4.4 Process Information Analysis

Subsequent to treatment process selection, details on each process were compiled and the process was translated into specific major unit operations and equipment for system evaluation and cost estimating efforts.

An inventory of major identifiable equipment was prepared for each process under study. Flow diagrams, equipment lists and factual information lists were compiled. In the equipment lists, each identified unit process or unit of equipment is indexed for grouping equipment in a treatment train. Each equipment item is assigned a 5-digit identification number; the first two digits identify the waste stream (01 through 18); the third digit defines the treatment train alternative (1 or 2) and the last two digits identify each unit operation or unit of equipment in the process train.

For those processes which are known and proven technologies, material balance and heat requirement information was obtained from industry and appropriate adjustments were made based on plant sizes. For processes which were highly conceptual in nature, available efficiency information on each unit of equipment and engineering judgements were used to generate material balances. The equipment inventories were used as working lists in preparing cost estimates for the fixed equipment and energy requirements.

1.4.5 Cost Analyses of Selected Treatments

Cost information contained in this report was assembled directly from industry, engineering firms, equipment suppliers, various cost curves in the literature, various chemical process plant cost publications and cost curves developed by the Contractor based on actual industrial installations. Cross-checks were made whenever information was available from different sources. The estimates presented were prepared on an engineering basis, using accepted engineering format.

The most referred to cost references in this study (other than direct information from companies using the particular processes and vendors of the particular machinery) were:

(1) Miller, H.E. "Costs of Process Equipment." Chemical Engineering March 16, 1974

(2) Parker, C.L. "Estimating the Cost of Wastewater Treatment Ponds." Pollution Engineering, Nov. 1975.

(3) Perry, R.H. and C.H. Chilton. Chemical Engineers Handbook, 5th Edition, McGraw Hill Book Co., N.Y., N.Y., pp. 19-72 to 19-86, pp. 20-23 to 20-44, pp. 20-120 to 20-121.

(4) Richardson Engineering Services, Process Plant Construction Estimating Standards, Vol. 4, 1975.

Appendix II details the cost bases for the cost analysis tasks. It should be noted that seventeen cost items were standardized and supplied by EPA. This was done to allow cost comparisons of similar "alternatives studies" being conducted by other contractors for different industries.

1.4.6 Cost Analysis of Land Disposal

Two land disposal options are costed in this study; sanitary landfill and chemical landfill, both operated by the waste generator. The land disposal costs are specific for each waste stream being generated by a typical size plant. The detailed design bases for both sanitary and chemical landfills for each waste stream are presented in Section 6.0 of this report. Sample calculations for land disposal options are presented as Appendix III.

1.4.7 Cost Comparisons

Capital investment and operating cost comparisons were made between selected treatment methods and the two land disposal options. These are discussed in detail in Section 7.0.

2.0 EXECUTIVE SUMMARY

2.1 Introduction

The manufacturing facilities in the inorganic chemicals industry were found to be disposing on land over 2 x 10^6 metric tons (dry basis) of potentially hazardous wastes annually. This was determined during EPA Contract 68-01-2246, where nineteen potentially hazardous waste streams were identified. More recently, EPA has sponsored another study aimed at defining possible alternative waste handling procedures (Contract No. 68-01-2288). While this latter study defines the potential utility of the various unit processes for the design and implementation of resource recovery, detoxification and volume reduction processes, it does not provide detailed designs of such systems. This study does provide background information that will aid subsequent investigators in selecting relevant treatment processes for specific waste streams.

The purpose of the present investigation is to assess alternatives to land disposal for potentially hazardous wastes generated by the inorganic chemicals industry. The objective is to identify and analyze promising resource recovery and detoxification oriented treatment techniques which are alternatives to currently practiced disposal methods.

2.2 Alternative Treatment Processes

Table 1 summarizes information on those processes which have already been technically demonstrated. All four treatment trains in this table are resource recovery processes. Processes 01100 and 01200 are for mercury bearing wastes (streams 1 and 2) generated by mercury cell plants in the chlor-alkali industry. Process 01100 is currently in use by one plant and process 01200 was used by another plant and shut down because of mechanical difficulties. The recommended process 01200 contains modifications to alleviate the mechanical difficulties and would require demonstration to ascertain its technical viability. Process 06100 is for sodium/calcium wastes (stream 6) generated by the Down's cell process used for sodium manufacture. This treatment process was used by one sodium manufacturer but was discontinued because of personnel safety and waste handling problems. The basic process, with some modification, is currently employed by another sodium plant. However, process details were not divulged.

Process 16B100 is a combination of several individually proven unit operations used by plants in the phosphorus industry. It is believed that this system would be technically viable and workable in the sequence of operations as proposed.

TABLE 1

SUMMARY OF TECHNICALLY DEMONSTRATED ALTERNATIVE TREATMENT SYSTEMS

Waste Generating Industry	Waste Stream No.	Treatment System		Unit Processes in Treatment Train[1,2,3,5]								Benefits Derived	Total Treatment Cost $/kkg of waste		Product Cost Impact $/kkg of product
		Identification Number	Feed Rate kkg/day	1	2	3	4	5	6	7	8		Wet Basis	Dry Basis	
Chlor-Alkali Mercury Cell	1 & 2	01100	19.5	Neut. C,V	Dis. C,IV	Filt. P, V	Sed. P,V	Preci. C, V	Filt. P, V	Dis. C, V	Neut. C, V	1) Mercury Recovery 2) Waste Reduction 3) Waste Detoxification	89	361	6.9
	1 & 2	01200	19.5	Sed. P,V	Filt. P,V	Calc. C, IV	Post Treat.	—	—	—	—	1) Mercury Recovery 2) Waste Reduction 3) Waste Detoxification	34[6]	143[6]	2.7
Sodium Mfg.	6	06100	1.82	Pre Treat	Elec C,III	Grind P, V	Dry P, V	—	—	—	—	1) Sodium Recovery 2) Cell bath Recovery 3) Waste elimination	—	3,170[7]	44
Phosphorus Mfg.	16B	16B100	18.3	Floc. P, V	Clar. P, V	Phase Sep. P, V	Dist. P, V	Post Treat.	—	—	—	1) Phosphorus Recovery 2) Waste Reduction	12	120	1.6

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[1] All unit processes are listed in the same order as recommended for treatment.

[2] Unit processes have been classified using "P" for physical separation and "C" for chemical transformation processes.

[3] ADL's categorization of I through V has been used to identify the developmental stage of each unit process used.

[4] For this application this unit operation can be categorized as "IV" since off-the-shelf pilot plant units would be adequate to treat this waste stream.

[5] Legend:

Neut - Neutralization
Dis - Dissolution
Filt - Filtration
Sed - Sedimentation
Preci- Precipitation

Calc - Calcination
Elec - Electrolysis
Grind - Grinding
Smelt - Smelting
Dry - Drying

Evap - Evaporation
Asph - Asphalting
HGMS - High Gradient Magnetic Separation
Floc - Flocculation
Sep - Separation
Dist - Distillation

[6] Average of systems 01200A and 01200B (multiple hearth vs. fluidized bed calcination.

[7] This waste stream contains no moisture. Therefore the treatment cost is given on dry basis only.

Table 2 presents the remaining selected treatment processes which are all of conceptual nature. These processes incorporate unit operations which represent technology transfer from other industries. Prior to implementation of any of these processes, research and development would be required to confirm their technical feasibility and establish their economic viability. Processes 04100 and 05100 are treatment processes for asbestos separator waste and lead-containing waste, respectively, both generated by diaphragm cell plants in the chlor-alkali industry. The lead-containing wastes can be eliminated by the use of dimensionally stable anodes (DSA) which are gradually replacing their graphite counterparts in existing plants. The asbestos wastes will be eliminated when plastic microporous separators, currently being tested by at least two facilities, become commercially practicable. However, according to the Chlorine Institute, transition to plastic separators will not be practical in the foreseeable future.

Of the sixteen treatment processes presented in Tables 1 and 2, seven (01100, 01200, 05100, 06100, 15100, 16B100 and 18100) offer both resource recovery and detoxification. However, with the exception of process 16B100, phosphorus recovery from phossy water streams, resource recovery is not a viable incentive to use the recommended processes for hazardous waste management in this industry. This is predicated on the low economic value of the small quantities of resources recovered. These treatment processes can only be justified with potentially hazardous waste detoxification as a prime objective and resource recovery as a secondary issue.

2.3 Costs for Land Disposal Options

Table 3 summarizes costs of sanitary and chemical landfills for the disposal of potentially hazardous waste streams generated by typical plants in the inorganic chemicals industry. As required, these costs were developed on the assumption that the landfills would be constructed and operated by the waste generator. The land disposal cost estimates for waste stream 6 (sodium/calcium wastes) are presented for information only because the highly explosive nature of this waste would preclude its disposal in this manner. With the exception of two proprietary treatment processes, these wastes are currently ocean dumped.

Table 3 generally indicates that the disposal costs for a given waste stream in a chemical landfill are greater than those in a sanitary landfill. The incremental annual operating costs of the chemical landfill over those of the sanitary landfill are relatively small for waste streams being generated at a rate less than three metric tons per day (waste streams 3, 4 and 5 combined and waste streams 8, 15, 17 and 18). However, for larger waste streams, the ratio of annual operating costs of the chemical landfill to the sanitary landfill is in the order of 2 to 4:1.

TABLE 2

SUMMARY OF CONCEPTUAL ALTERNATIVE TREATMENT SYSTEMS

Waste Generating Industry	Waste Stream No.	Treatment System		Unit Processes in Treatment Train[1,2,3,5]					Benefits Derived	Total Treatment Cost $/kkg of waste		Product Cost Impact $/kkg of product
		Identification Number	Feed Rate kkg/day	1	2	3	4	5		Wet Basis	Dry Basis	
Chlor-Alkali Diaphragm Cell	3	Eliminated		—	—	—	—	—	—	—	—	—
	4	04100	2.27	Pre Treat.	Dry. P, V	Calc. C, IV	—	—	1) Detoxification	144	545	2.0
	5	05100	5.8	Floc. P, V	Filt. P, V	Calc./ Smelt. C, IV	—	—	1) Lead Recovery 2) Waste Reduction			
Titanium Dioxide Chloride Process	7	07100	2,800	Floc. P, V	Sed. P, V	Filt. P, V	Calc. C, IV	Post Treat.	1) Waste Detoxification 2) Waste Reduction	6.9	138	193
Chrome Pigment Manufacturing	8	08100	4.2	Pre Treat.	Calc. C,IV	Post Treat.	—	—	1) Waste Detoxifi- 2) Waste Reduction	342	450	45
	8	08200	4.2	Evap & Asph. P, IV	Post Treat.	—	—	—	1) Waste Detoxification 2) Production of Water Suitable for Discharge	167	220	22
Hydrofluoric Acid Mfg.	9	09100	420	Evap.& Asph. P, IV	Post Treat.	—	—	—	1) Waste Detoxification 2) Production of Water Suitable for Discharge	77	96	360
Boric Acid Mfg.	10	Eliminated		—	—	—	—	—	—	—	—	—

[1] All unit processes are listed in the same order as recommended for treatment.

[2] Unit processes have been classified using "P" for physical separation and "C" for chemical transformation processes.

[3] ADL's categorization of I through V has been used to identify the developmental stage of each unit process used.

[4] For this application this unit operation can be categorized as "IV" since off-the-shelf pilot plant units would be adequate to treat this waste stream.

[5] Legend:

Neut - Neutralization
Dis - Dissolution
Filt - Filtration
Sed - Sedimentation
Preci- Precipitation

Calc - Calcination
Elec - Electrolysis
Grind - Grinding
Smelt - Smelting
Dry - Drying

Evap - Evaporation
Asph - Asphalting
HGMS - High Gradient Magnetic Separation
Floc - Flocculation
Sep - Separation
Dist - Distillation

[6] Average of systems 01200A and 01200B (multiple hearth vs. fluidized bed calcination.

[7] This waste stream contains no moisture. Therefore the treatment cost is given on dry basis only.

TABLE 2

SUMMARY OF CONCEPTUAL ALTERNATIVE TREATMENT SYSTEMS (continued)

Waste Generating Industry	Waste Stream No.	Treatment System		Unit Processes in Treatment Train[1],[2],[3],[5]					Benefits Derived	Total Treatment Cost $/kkg of waste		Product Cost Impact $/kkg of product
		Identification Number	Feed Rate kkg/day	1	2	3	4	5		Wet Basis	Dry Basis	
Aluminum Fluoride Mfg.	11	11100	46.2	Evap.& Asph. P, IV	Post Treat.	--	--	--	1) Waste Detoxification 2) Production of Water Suitable for Discharge	74	94	17
Antimony Mfg.	12	Waste No Longer Generated		—	—	--	--	--		—	—	—
Sodium Silicofluoride Mfg.	13	13100	32.2	Evap.& Asph. P, IV	Post Treat.	—	—	--	1) Waste Detoxification 2) Waste Reduction 3) Production of Water Suitable for Discharge	75	247	38
Chromates Mfg.	14	14100	200	Pre Treat.	Calc. C, IV	Post Treat.	--	--	1) Waste Detoxification 2) Waste Reduction	54	72	59
Nickel Sulfate Mfg.	15	15100	1	Pre Treat.	HCMS P,II[6]	--	—	--	1) Nickel hydroxide Recovery 2) Waste Detoxification	212	424	25
Phosphorus Mfg.	16A	16A100	118	Evap.& Asph. P, IV	Post Treat.	--	—	--	1) Waste Detoxification 2) Production of Water Suitable for Discharge	91	151	56
Phosphorus Pentasulfide Mfg.	17	Eliminated		--	--	--	--	--	--	—	--	--
Phosphorus Trichloride Mfg.	18	18100	0.23	Dist. P, V	Post Treat.	--	—	—	1) Waste Detoxification 2) Impure $AsCl_3$ Recovery	—	1,740[7]	1.0

TABLE 3

SUMMARY OF COST FOR LAND DISPOSAL OPTIONS

Waste Generating Industry	Waste Stream No.	Sanitary Landfill			Chemical Landfill			Incineration	
		Total Disposal Cost $/kkg of waste		Product Cost Impact $/kkg of product	Total Disposal Cost $/kkg of waste		Product Cost Impact $/kkg of product	Total Cost $/kkg of waste	Product Cost Impact $/kkg of product
		Wet Basis	Dry Basis		Wet Basis	Dry Basis			
Chlor-Alkali									
Mercury cell	1 & 2	17	70	1.30	34	140	2.65	—	—
Diaphragm cell	3, 4 & 5	47	164	0.68	63	219	0.91	—	—
	3, 4 & 5	52[1]	183[1]	0.76[1]	66[1]	228[1]	0.95[1]	220.5[1]	0.1[2]
	4 & 5	47	178	0.66	60	229	0.85	—	—
Sodium	6	—	72 (41)[3,4]	0.94 (0.53)[3]	—	100[4]	1.30	—	—
Titanium Dioxide	7B	1.1	21	29	2.6	71	99	—	—
Chrome Color and Inorganic Pigments	8	99	129	13	107	140	14	—	—
Hydrofluoric Acid	9	5.09	6.36	24	15	18	68	—	—
Aluminum Fluoride	11	13	16	2.93	23	29	5.19	—	—
Sodium Silicofluoride	13	22	73	11	35	115	18	—	—
Chromate	14	7.01	9.35	7.70	14	19	15	—	—
Nickel Sulfate	15	98 (41)	196 (81)[3]	11 (5)[3]	118	237	13	—	—
Phosphorus	16A & 16B	15	30	11	55	108	42	—	—
	16B	60	609	8	178	1,810	24	—	—
Phosphorus Pentasulfide	17	—	215 (45)[3,4]	0.43 (0.09)[3]	—	236[4]	0.47	—	—
Phosphorus Trichloride	18	—	362 (36)[3,4]	0.36 (0.04)[3]	—	389[4]	0.39	—	—

[1] Costs for this option assume sanitary landfill or chemical landfill for the lead and asbestos sludges (streams 4 & 5) and contract incineration of the chlorinated hydrocarbons (stream 3).

[2] Contract incineration of stream 3, chlorinated hydrocarbons.

[3] Costs given in the parenthesis are based on contract operated sanitary facilities which are owned by the waste generator.

[4] This waste is moisture free. Therefore, costs per metric ton of waste is given for dry basis only.

Contract incineration of waste stream 3 (chlorinated hydrocarbons) appears attractive because it is a relatively low cost operation and centralized facilities or on-site incinerators are sometimes available. The chlorinated hydrocarbon waste stream is formed from the reaction of chlorine with the binders in graphite anodes and will be reduced with the use of dimensionally stable anodes.

2.4 Cost Comparisons of Alternate Treatment Processes to the Landfill Options

Table 4 presents capital investment and annual operating costs for the alternate treatment processes and compares them to the costs for plant operated landfills.

2.5 Effect of Treatment Cost on Product Price

Table 5 presents the effect of treatment and land disposal costs on product prices assuming that these costs would be passed on to the consumer. With the exception of one calcination system (07100) and three evaporation and asphalting systems (09100, 13100 and 16A100) which are highly energy intensive and require large capital outlays, the incremental increase on product price would be under 10%. In eleven of the sixteen treatment systems, the incremental increase in product price would be under 5%. In one treatment system (09100) where the incremental increase is of the order of 40%, it is highly questionable that evaporation and asphalting would be practical. This system would consume enormous quantities of asphalt which may be unavailable in the future because of current petroleum shortages. There would also be a need for new landfills to dispose of the asphalted solids, if this material proves to be unsuitable for use as road paving aggregate.

Comparison of the effects on product price of treatment, sanitary landfilling and chemical landfilling costs indicate that:

(a) the ratios of treatment costs to sanitary landfilling costs range from 1.8 to 83:1 with the average ratio 4.3:1

(b) the ratios of treatment costs to chemical landfilling costs range from 1 to 34:1 with the average ratio 2.4:1

The notable exception is waste stream 16B where the ratios of treatment costs to land disposal option costs are considerably less than one; 0.17 and 0.056 for sanitary landfilling and chemical landfilling, respectively.

When comparing the two land disposal options chemical landfilling costs increase product costs more than sanitary landfilling by an average factor of about 2.

TABLE 4

COST COMPARISONS FOR ALTERNATE TREATMENT SYSTEMS AND LANDFILL OPTIONS

INDUSTRY	Waste Stream No.	Treatment System Identification No.	CAPITAL INVESTMENT (MM $)			ANNUAL OPERATING COSTS ($)		
			Treatment System	Sanitary Landfill	Chemical Landfill	Treatment System	Sanitary Landfill	Chemical Landfill
Chlor-Alkali Plants								
a. Mercury Cell operations	1 & 2	01100	1.54	0.171	0.707	626,300	118,890	246,430
	1 & 2	01200	0.66[1]	0.171	0.707	246,360[1]	118,890	246,430
b. Diaphragm Cell operations	4 5	04100 & 05100	0.525	0.134	0.268	335,575	108,650	139,800
Sodium Plants	6	06100	1.409	0.103 (0.010)[2]	0.152	2,262,600	47,990 (27,220)[2]	66,460
Titanium Dioxide, Chloride process	7	07100	13.257	3.150	14.020	7,046,500	1,068,360	3,608,050
Chrome Pigment Plants	8	08100	1.066	0.117	0.159	374,750	107,980	117,600
	8	08200	0.195	0.117	0.159	183,825	107,980	117,600
Hydrofluoric Acid	9	09100	2.691	1.401	5.854	8,422,550	557,000	1,592,700
Aluminum Fluoride	11	11000	0.261	0.282	0.795	893,200	154,820	274,450
Sodium Silicofluoride	13	13100	0.383	0.228	0.691	631,150	186,040	293,740
Chromates	14	14100	4.914	1.010	3.688	3,911,300	511,720	1,077,050
Nickel Sulfate	15	15100	0.099	0.086 (0.005)[2]	0.118	77,300	35,740 (14,880)[2]	43,220
Phosphorus	16A&16B	16A100 & 16B100	1.421	0.635	4.993	2,874,050	570,000	2,061,250
	16B alone	16B100	0.544	0.208	1.702	80,400	400,040	1,189,400
Phosphorus Trichloride	18	18100	0.046	0.071 (0.001)[2]	0.078	104,540	21,130 (2,110)[2]	22,700

[1] Average of systems 01200A and 01200B (multiple hearth vs. fluidized bed calciner).

[2] Contractor operated sanitary landfill.

TABLE 5

EFFECT OF TREATMENT AND LAND DISPOSAL COSTS ON PRODUCT PRICE

Product	Product Price 1976, \$/kkg[1]	Waste Stream	Waste Treatment System	Treatment Cost, \$/kkg of Product	Percent of Product Price	Sanitary Landfill Cost, \$/kkg of Product	Percent of Product Price	Chemical Landfill Cost, \$/kkg of Product	Percent of Product Price
Chlorine[7]	165	1 & 2	01100	6.9	4.2	1.3	0.8	2.7	1.6
Chlorine[7]	165	1 & 2	01200[2]	2.7[2]	1.6	1.3	0.8	2.7	1.6
Chlorine[7]	165	3, 4 & 5[3]	---	---	---	0.68	0.4	0.91	0.6
Chlorine[7]	165	4 & 5	04100 & 05100	2.0	1.2	0.66	0.4	0.85	0.5
Sodium	638	6	06100[4]	44	6.9	0.53	0.08	1.3	0.2
Titanium Dioxide	1,055	7B	07100	193	18.3	29.3	2.8	98.9	9.4
Chrome Pigments	2,045	8	08100	45	2.2	[illegible]	0.6	14.0	0.7
Chrome Pigments	2,045	8	08200	22	1.1	12.9	0.6	14.0	0.7
Hydrofluoric Acid	902	9	09100	360	40.0	23.8	2.7	68.2	7.6
Aluminum Fluoride	385	11	11100	17	4.4	2.9	0.8	5.2	1.3
Sodium Silicofluoride	220	13	13100	38	17.3	11.3	5.2	17.9	8.1
Chromates	637	14	14100	59	9.3	7.7	1.2	15.6	2.4
Nickel Sulfate	1,670	15	15100	25	1.5	4.5[5]	0.3	13.2	0.8
Phosphorus	1,340	16A	16A100	56	4.2	5.9	0.4	18.9	1.4
Phosphorus	1,340	16B	16B100	1.6	0.1	8.1	0.6	24.0	1.8
Phosphorus	1,340	16A & B[3]	---	57	4.2	11.5	0.9	41.5	3.1
Phosphorus Pentasulfide	770	17[6]	---	---	---	0.09[5]	0.01	0.47	0.06
Phosphorus Trichloride	815	18	18100	1.8	0.2	0.04[5]	0.005	0.39	0.05

[1] Source: Chemical Marketing Reporter 1976. Where price was given as a range, the high value was used.

[2] Average of systems 01200A and 01200B (multiple hearth vs. fluidized bed calciner).

[3] There is no alternate treatment process for these combined streams; only sanitary and chemical landfill options are shown.

[4] Landfilling of this waste is highly conceptual since this waste is extremely flammable and explosive should it be contacted by moisture.

[5] This cost is for very small streams where the company-owned sanitary landfill is operated intermittently by an outside contractor. This cost is significantly smaller than if the waste generator were to operate the landfill. The latter cost for the cases involved ranges from 2 to 9 times larger than the outside contractor cost.

[6] There is no alternate treatment process for this stream.

[7] Treatment and land disposal costs were applied to the chlorine product only and not shared with the sodium hydroxide by-product.

3.0 MAJOR SOLID WASTE PROBLEM AREAS IN THE INORGANIC CHEMICALS INDUSTRY

3.1 Introduction

The inorganic chemicals industry is comprised of those facilities manufacturing products categorized according to SIC Codes 2812, 2813, 2816 and 2819. Hundreds of products and processes are involved and facilities range from small specialty chemical operations producing one or two chemicals to large integrated facilities producing many products.

Within this industry, there are about 20 product classifications which are responsible for most of the potentially hazardous land destined wastes generated. In an earlier study under EPA Contract No. 68-01-2246, an in-depth study of this industry was performed characterizing the wastes and describing presently used technology for handling and disposal of these wastes. The problem areas identified in the inorganic chemicals industry are discussed below.

3.2 Identification of Problem Areas

Within the inorganic chemicals industry there are several major land-destined solid waste problem areas where improvements in disposal or reuse practices could significantly reduce the amounts of potentially hazardous materials currently disposed of in landfills. Major problem areas identified under Contract No. 68-01-2246 are listed below:

Stream 1 - Mercury contaminated brine purification muds - mercury cell process, chlor-alkali production;

Stream 2 - Mercury-rich wastes from treatments and cleanings - mercury cell process, chlor-alkali production;

Stream 3 - Chlorinated hydrocarbons - diaphragm cell process, chlor-alkali production;

Stream 4 - Asbestos separator wastes - diaphragm cell process, chlor-alkali production;

Stream 5 - Lead-containing wastes - diaphragm cell process, chlor-alkali production;

Stream 6 - Metallic sodium and calcium filter cake - Down's cell process, metallic sodium production;

Stream 7 - Sludges from wastewater treatment - chloride process titanium dioxide production;

Stream 8 - Sludges from wastewater treatment - chrome color and inorganic pigment production;

Stream 9 - Fluoride-containing gypsum waste - hydrofluoric acid production;

Stream 10 - Arsenic-containing sludges - boric acid production;

Stream 11 - Fluoride-containing wastewater treatment sludge - aluminum fluoride production;

Stream 12 - Antimony waste stockpile - antimony production;

Stream 13 - Fluoride wastes - sodium silicofluoride production;

Stream 14 - Chromate contaminated wastes - chromate production;

Stream 15 - Nickel wastes from wastewater treatment - nickel sulfate production;

Streams 16A and 16B - Fluoride bearing sludge from phosphate rock calcining kiln and electric furnace and phossy water from phosphorus condenser, respectively - furnace process, phosphorus production;

Stream 17 - Arsenic and phosphorus wastes - phosphorus pentasulfide production; and

Stream 18 - Arsenic trichloride waste - phosphorus trichloride production.

The characteristics and composition of these waste streams from typical plants in each industry category are summarized in Table 6. A brief description of each stream follows, accompanied by mass balanced flow diagrams quantifying inputs and outputs on the basis of 1,000 mass units of the principal product.

3.3 Description and Characterization of Potentially Hazardous Waste Streams

3.3.1 Chlor-Alkali Manufacture

3.3.1.1 General Characterization of the Industry

There are 34 companies in 66 locations engaged in chlorine and sodium hydroxide or potassium hydroxide manufacture by either the mercury cell process or diaphragm cell process. The total annual capacity of these plants is 20,483 kkg (22,513 tons).[88]

3.3.1.2 Description of Potentially Hazardous Waste Streams

a. Mercury Cell Process

The typical mercury cell plant has a production rate of 250 kkg (275 tons) per day and is 5 to 30 years old. There are several waste streams generated by this process, two of which are considered to be potentially hazardous:

1. Brine purification muds - These are often contaminated with mercury in a typical amount of 0.05 kg/kkg of chlorine produced with a range of 0 - 0.15 kg/kkg. Whether or not these muds are potentially hazardous varies from plant to

TABLE 6

THE CHARACTERISTICS AND COMPOSITION OF SOLID WASTE STREAMS GENERATED BY THE INORGANIC CHEMICALS INDUSTRY

Waste Stream Description	Mercury Contaminated Muds-Mercury Cell	Mercury Waste from Treatment & Cleaning of Mercury Cell	Chlorinated HC-Mercury & Diaphragm Cell	Asbestos Separator Wastes - Diaphragm Cell	Lead-Containing Waste - Diaphragm Cell	Metallic Sodium & Calcium sludges - Downs Cell	Solids from Wastewater Treatment - Titanium Dioxide, Chloride Process, Rutile Ore
Waste Stream Number	1	2	3	4	5	6	7A
Physical form	sludge	sludge	sludge	sludge	sludge	metal (no H_2O) sludge	sludge
Size of typical plant, kkg/day	250	250	450	450	450	140	100
Hazardous Components, Quantity on dry basis kkg/day	Hg as metal, chloride & sulfide 0.0	Mercury sulfide	0.2 chlorinated HC	0.18 asbestos	0.09 lead (metal and carbonates) 0.045 asbestos	1.82 sodium & calcium sludge	0.13 $Cr(OH)_3$
Non-Hazardous Components kkg/day	4.25 $CaCO_3$, $Mg(OH)_2$, $BaSO_4$, NaCl 14.75 water	0.5 graphite filter aid 0.5 water	none	1.35 carbon & rubble 0.66 water	4 water	0.1 CaO 0.3 Na_2O Traces of NaCl & $CaCl_2$	1.6 ore residue 3.7 coke 0.3 silica 21 misc. hydroxide 83 water
Total Stream, dry basis kkg/day	4.29	0.5	0.2	1.53	0.14	2.22	27
Total Stream, moisture included kkg/day	10.5[1]	1	no water	2.19	4.14	no water	110[2]
No. of Plants	28		38			5	6[3]

[1] This sludge would be thickened to a solid level of about 39 wt.% prior to landfilling.

[2] Assumes that the sludge is thickened prior to landfilling.

[3] This number includes plants that are using upgraded Ilmenite ore containing 75% titanium dioxide wastes generated by this category of plants is greater than that shown for stream 7A and less than that shown for stream 7B.

[4] Numbers in this column are on annual basis.

TABLE 6
THE CHARACTERISTICS AND COMPOSITION OF SOLID WASTE STREAMS GENERATED BY THE INORGANIC CHEMICALS INDUSTRY (Contd.)

Waste Stream Description	Solids from Wastewater Treatment - Titanium Dioxide, Chloride Process, Ilmenite ore	Sludges from Wastewater Treatment - Chrome Color & inorganic pigment mfg.	Gypsum Waste - HF acid mfg.	Arsenic-Containing Sludges - Boric acid Mfg.	Wastewater Treatment Sludge - AlF_3 Mfg.	Antimony Waste Stockpile - Antimony Mfg.	Fluoride Wastes - Sodium Silicofluoride Mfg.
Waste Stream Number	7B	8	9	10	11	12	13
Physical form	sludge	sludge	sludge	sludge	sludge	This waste stream is no longer generated. The company has changed the raw material and uses an impure antimony oxide which contains no As_2S_3	sludge
Size of Typical plant kkg/day	100	23	64	110	145		45
Hazardous Components, Quantity on dry basis kkg/day	0.13 $Cr(OH)_3$	0.2 $Cr(OH)_3$ 0.6 $PbCrO_4$ 0.06 $Pb(OH)_2$ 0.1 ZnO 0.06 $Fe(CN)_3$	7 CaF_2	0.02-0.5 kg/day - As containing waste	12 CaF_2		2.6-4.5 CaF_2
Non-Hazardous Components, kkg/day	2.5 ore residue 6.8 coke 0.6 silica 130 misc. hydroxide 420 water	1.28 Fe_2O_3, $CaSO_4$, $Fe(OH)_3$ 0.7 water	233 $CaSO_4$, silica 60 water	0.16-0.4 filter aid 0.04-0.1 water	10 $CaSO_4$ 4 hydrated lime 7 water		2.5 - 4.4 silica, salt, hydrated lime 16 water
Total Stream, dry basis kkg/day	140	2.3	240	0.16-0.4	26		7
Total Stream, moisture included kkg/day	560[2]	3	300	0.2-0.5	33		23
No. of Plants	2	16	16	1	4	1	4

TABLE 6

THE CHARACTERISTICS AND COMPOSITION OF SOLID WASTE STREAMS GENERATED BY THE INORGANIC CHEMICALS INDUSTRY (contd.)

Waste Stream Description	Chromate Contaminated-chromate Mfg.	Nickel Waste from Waste-water Treatment $NiSO_4$ Mfg.	Fluoride Waste - Phosphorus Mfg.	Phossy Water-Phosphorus Mfg.	Arsenic & Phosphorus Wastes - P_2S_5 Mfg.	$AsCl_3$ Waste - PCl_3 Mfg.
Waste Stream Number	14	15	16A	16B	17*	18*
Physical form	muds & sludges	sludge	sludge	phossy water	dry residues and dust	dry residues
Size of Typical plant, kkg/day	182	9	136	136	55,000	58,000
Hazardous Components, Quantity on dry basis kkg/day	0.025 $Cr(OH)_3$ 0.005 Chromate	0.7 kg/day $Ni(OH)_2$	8.8 CaF_2	1.2 phosphorus	3 As_2S_3 8 Phosphorus & phosphorus sulfide	3 $AsCl_3$
Non-Hazardous Components kkg/day	150 Ore residue includes oxide and carbonates of Fe, Si and Mg plus Ca salts & $Al(OH)_3$ 50 Water	0.5 filter aid unknown small quantity of organic material 0.5 Water	1.8 CaO 5.0 SiO_2 4.5 $Ca_3(PO_4)_2$ 30.6 $CaSO_4$ 33.6 Water	0.6 suspended solids 16.5 water	108 glassy phosphate, Fe_2S_3	57 glassy phosphate, $FeCl_3$
Total Stream, dry basis kkg/day	150	0.5	50.7	1.8	119	60
Total Stream, moisture included kkg/day	200	1	84.3	18.3	no water	no water
No. of Plants	6	7	9	9	7	6

plant in this industry depending on process details. They range from no mercury content to 5000 ppm.

2. Mercury sludges from treatment of effluent wastewaters to remove entrained elemental mercury. The mercury is generally precipitated as the sulfide. The mercury content is typically 0.058 kg/kkg of chlorine.

The chlorinated hydrocarbon problem is being solved at mercury cell plants by replacing graphite anodes by coated metal anodes [dimensionally stable anodes (DSA)]. However, the use of DSA may not completely eliminate this problem because equipment may still contain rubber lining and other sources of trace quantities of hydrocarbons that could react with chlorine.

A general process diagram showing waste sources is given in Figure 1.

b. Diaphragm Cell Process

The typical diaphragm cell plant has a production rate of 450 kkg (500 tons) per day. However, the trend in recent times has been to very large plants with capacities greater than 907 kkg (1,000 tons) per day. The typical plant, while also 5 to 30 years old, is relatively newer than a mercury-cell plant. There are three potentially hazardous waste streams (streams 3, 4 and 5) being generated at these plants:

1. Chlorinated hydrocarbon wastes - These arise from reaction of chlorine with carbonaceous materials in the electrodes, oils and greases present in the equipment and other hydrocarbons present. These materials are presently separated from the product and are disposed of either by landfilling in sealed drums, deep well disposal or incinerated. An approach currently used by industry to reduce this waste stream is the use of dimensionally stable metal anodes. This approach has been implemented at several facilities. However, based on discussions with industry, complete changeover may not be attained for at least a decade. Because the chlorinated hydrocarbons generated at these plant sites are mixed materials with a consistency of oily to tar-like material, they are not amenable to resource recovery. The best technology for control of these wastes is incineration. Since incineration is not one of the 43 treatment processes studied under Contract No. 68-01-2288, this waste stream is being eliminated from further consideration in this study.
2. Asbestos separator wastes from cell diaphragms - These wastes arise from disposal of spent diaphragms which are normally used in the industry. An approach currently being considered by industry to eliminate this waste stream is to replace asbestos with plastic membranes. However, based on discussions with the industry, these replacements will not be practicable in the foreseeable future.

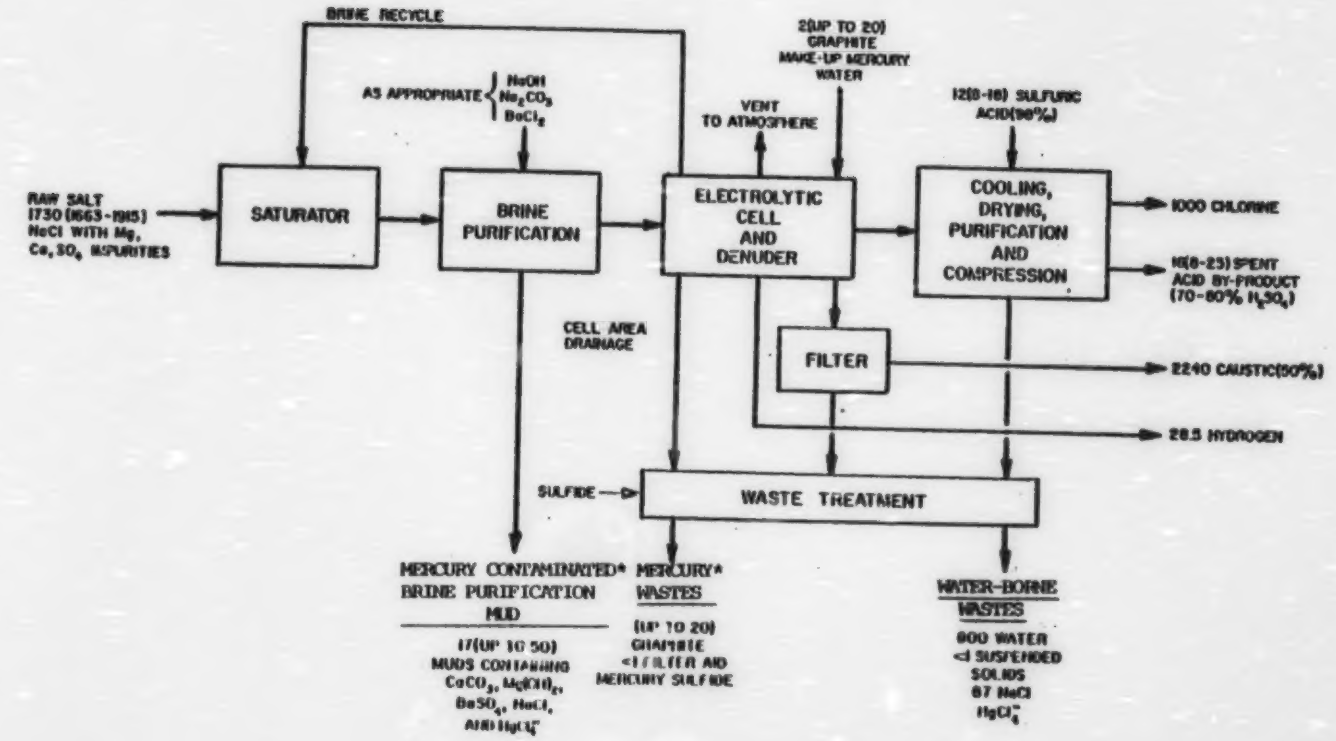

BRINE RECYCLE
RAW SALT 1730 (1663-1915) NaCl WITH Mg, Ca, SO_4 IMPURITIES
SATURATOR
AS APPROPRIATE { NaOH Na_2CO_3 $BaCl_2$
BRINE PURIFICATION
VENT TO ATMOSPHERE
2(UP TO 20) GRAPHITE MAKE-UP MERCURY WATER
ELECTROLYTIC CELL AND DENUDER
12(8-18) SULFURIC ACID(98%)
COOLING, DRYING, PURIFICATION AND COMPRESSION
1000 CHLORINE
11(8-23) SPENT ACID BY-PRODUCT (70-80% H_2SO_4)
CELL AREA DRAINAGE
FILTER
2240 CAUSTIC(50%)
28.5 HYDROGEN
SULFIDE
WASTE TREATMENT
MERCURY CONTAMINATED* BRINE PURIFICATION MUD
17(UP TO 50) MUDS CONTAINING $CaCO_3$, $Mg(OH)_2$, $BaSO_4$, NaCl, AND $HgCl_4^=$
MERCURY* WASTES
(UP TO 20) GRAPHITE <1 FILTER AID MERCURY SULFIDE
WATER-BORNE WASTES
800 WATER <1 SUSPENDED SOLIDS 87 NaCl $HgCl_4^=$

Figure 1 CHLOR-ALKALI MANUFACTURE, MERCURY CELL PROCESS

*Potentially hazardous land destined wastes

3. Lead salts resulting from wastewater treatment - The lead arises in the effluent due to cell breakdown and corrosion. Treatment of the waterborne wastes precipitates lead carbonate, which is then land disposed as a sludge. Conversion to DSA would also eliminate this waste.

A flow diagram for the diaphragm cell process, showing waste sources, is given in Figure 2.

3.3.2 Sodium Manufacture

3.3.2.1 General Characterization of the Industry

There are 3 companies in 5 locations engaged in sodium manufacture by the Down's Cell process. The total annual capacity of these plants is 343,000 kkg (378,000 tons).[88] The typical sodium plant has a production rate of 140 kkg (154 tons) per day.

3.3.2.2 Description of Potentially Hazardous Waste Streams

There are several wastes generated by the manufacture of sodium by the Down's Cell process. However, only one is considered potentially hazardous. This waste, a sodium-calcium filter cake, arises from the filtration of product sodium and typically amounts to 2.2 kkg (2.4 tons) per day. This waste is considered extremely hazardous because of its violent reactivity with water and must be disposed of under carefully controlled conditions to avoid explosions or fires. The flow diagram for the Down's Cell process, showing waste sources, is given in Figure 3.

3.3.3 Titanium Dioxide, Chloride Process

3.3.3.1 General Characterization of the Industry

There are 5 companies in 8 locations engaged in the manufacture of titanium dioxide by the chloride process. The total annual capacity of these plants in 1975 was 492,600 kkg (544,000 tons).[92] A typical chloride process titanium dioxide plant has a production rate of 100 kkg (110 tons) per day.

3.3.3.2 Description of Potentially Hazardous Waste Streams

The manufacture of titanium dioxide by the chloride process involves the chlorination of rutile or ilmenite ore in the presence of coke, oxidation of intermediate titanium tetrachloride, and further purification and finishing steps. This process generates two solid waste streams. However, only the sludge, containing heavy metal hydroxides, is considered potentially hazardous. This sludge is generated by the treatment of the acidic, heavy metal salt-containing waterborne waste streams and typically contains 0.13 kkg (0.14 tons) per day of chromium hydroxide. Although the use of either rutile or ilmenite ore results in about the same quantity of this hazardous component in the waste stream, the amounts of non-hazardous components generated from ilmenite are much greater and cause additional

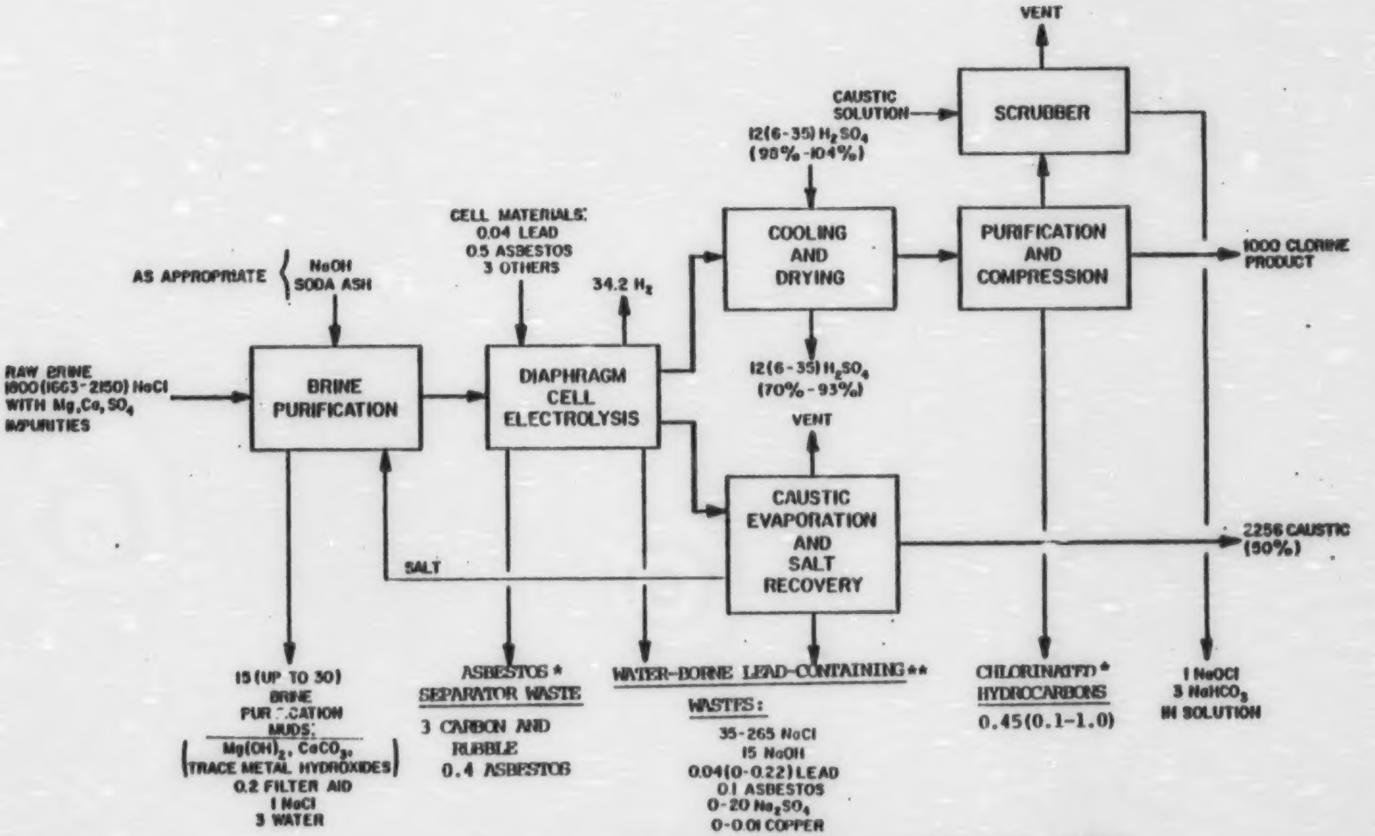

VENT
CAUSTIC SOLUTION
SCRUBBER
12(6-35) H_2SO_4 (98%-104%)
CELL MATERIALS: 0.04 LEAD 0.5 ASBESTOS 3 OTHERS
COOLING AND DRYING
PURIFICATION AND COMPRESSION
1000 CLORINE PRODUCT
AS APPROPRIATE NaOH SODA ASH
34.2 H_2
RAW BRINE 1800(1663-2150) NaCl WITH Mg,Ca,SO_4 IMPURITIES
BRINE PURIFICATION
DIAPHRAGM CELL ELECTROLYSIS
12(6-35) H_2SO_4 (70%-93%)
VENT
CAUSTIC EVAPORATION AND SALT RECOVERY
2256 CAUSTIC (50%)
SALT
15(UP TO 30) BRINE PUR.:CATION MUDS: ($Mg(OH)_2$, $CaCO_3$, TRACE METAL HYDROXIDES) 0.2 FILTER AID 1 NaCl 3 WATER
ASBESTOS * SEPARATOR WASTE
3 CARBON AND RUBBLE
0.4 ASBESTOS
WATER-BORNE LEAD-CONTAINING** WASTES:
35-265 NaCl
15 NaOH
0.04(0-0.22) LEAD
0.1 ASBESTOS
0-20 Na_2SO_4
0-0.01 COPPER
CHLORINATED * HYDROCARBONS
0.45(0.1-1.0)
1 NaOCl
3 $NaHCO_3$
IN SOLUTION

Figure 2 CHLOR-ALKALI MANUFACTURE, DIAPHRAGM CELL PROCESS

*Potentially hazardous land destined wastes

**Treatment of these wastes precipitates lead carbonate, which is then land disposed as sludge

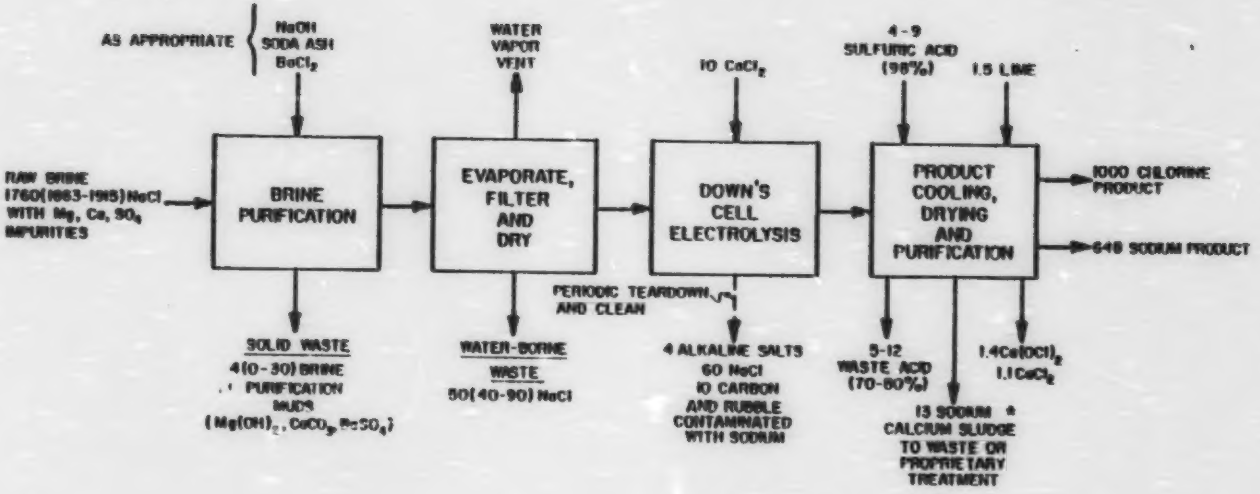

AS APPROPRIATE
NaOH
SODA ASH
BaCl$_2$
WATER
VAPOR
VENT
10 CaCl$_2$
4 - 9
SULFURIC ACID
(98%)
1.5 LIME
RAW BRINE
1760(1683-1915) NaCl
WITH Mg, Ca, SO$_4$
IMPURITIES
BRINE
PURIFICATION
EVAPORATE,
FILTER
AND
DRY
DOWN'S
CELL
ELECTROLYSIS
PRODUCT
COOLING,
DRYING
AND
PURIFICATION
1000 CHLORINE
PRODUCT
648 SODIUM PRODUCT
PERIODIC TEARDOWN
AND CLEAN
SOLID WASTE
4(0-30) BRINE
PURIFICATION
MUDS
(Mg(OH)$_2$, CaCO$_3$, BaSO$_4$)
WATER-BORNE
WASTE
50(40-90) NaCl
4 ALKALINE SALTS
60 NaCl
10 CARBON
AND RUBBLE
CONTAMINATED
WITH SODIUM
5-12
WASTE ACID
(70-80%)
13 SODIUM *
CALCIUM SLUDGE
TO WASTE OR
PROPRIETARY
TREATMENT
1.4Ca(OCl)$_2$
1.1CaCl$_2$

FIGURE 3

SODIUM AND CHLORINE MANUFACTURE
DOWN'S CELL PROCESS

*Potentially hazardous land destined waste

treatment problems. Only this larger waste stream is considered in this study. A flow diagram for this process is given in Figure 4.

3.3.4 Chrome Colors and Inorganic Pigment Manufacture

This industry subcategory includes two broad groupings of pigments; chrome colors and other inorganic pigments. The chrome colors include chrome yellows and oranges, molybdate chrome orange, zinc yellow, anhydrous and hydrated chrome oxide greens, chrome green and iron blue (not a chrome pigment, but usually produced in chrome pigment complexes). The other inorganic pigments include barium sulfate, cadmium colors, colored lead pigments, cobalt colors, iron oxide pigments, carbon black and mercury sulfide.

The manufacture of all pigments in the chrome color group and iron blues generates potentially hazardous wastes destined for land disposal. Only cadmium colors of the other inorganic pigment group contribute potentially hazardous wastes. However, this latter waste is normally recycled back to the process in those facilities manufacturing only cadmium colors.

3.3.4.1 General Characterization of the Industry

The chrome colors and iron blues industry consists of about 13 companies, many of which produce several of these chemicals. A typical plant has a daily production capacity of 23 kkg (25 tons).

3.3.4.2 Description of Potentially Hazardous Waste Streams

Flow diagrams for the manufacture of various chrome colors and iron blues are given in Figures 5 through 9. As shown, practically all of the land destined waste streams are sludges resulting from wastewater treatment. In most cases, the wastewaters are chemically treated to remove chromates, lead and zinc. These materials are precipitated as lead chromate, chromium (III) hydroxide and lead and zinc hydroxides, carbonates or sulfides. The handling of these solids varies considerably. In some cases, they are left in settling lagoons, while in others, they are landfilled. The land destined wastes from a typical plant could contain the following hazardous components:

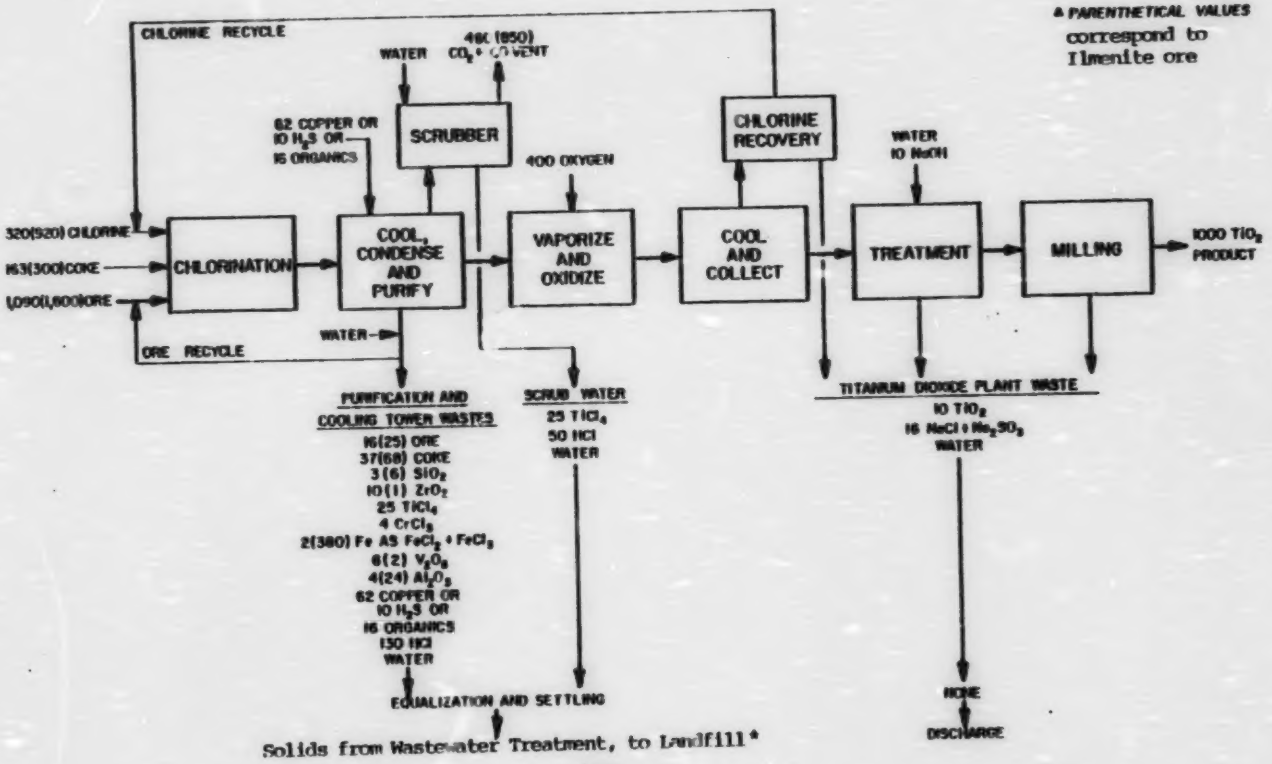
0.2 kkg (0.22 tons)/day $Cr(OH)_3$

0.6 kkg (0.66 tons)/day $PbCrO_4$

0.06 kkg (0.066 tons)/day $Pb(OH)_2$

0.1 kkg (0.11 tons)/day $Zn(OH)_2$

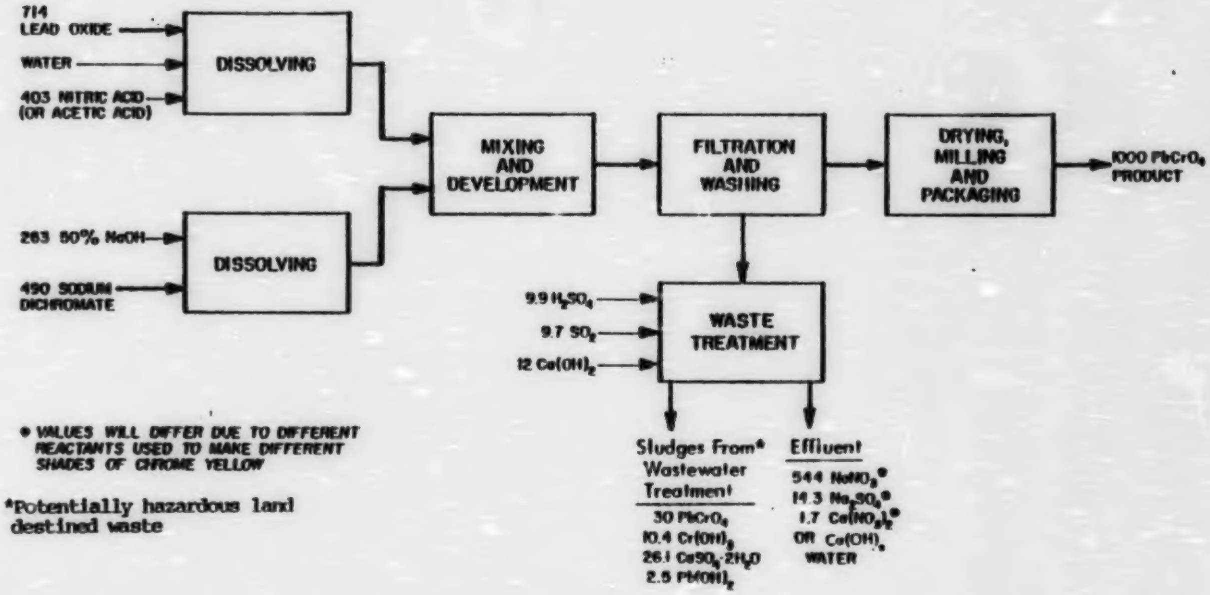
0.06 kkg (0.066 tons)/day $Fe_4[Fe(CN)_6]_3$


CHLORINE RECYCLE
320(920) CHLORINE
163(300) COKE
1,090(1,600) ORE
ORE RECYCLE
CHLORINATION
62 COPPER OR
10 H_2S OR
16 ORGANICS
COOL, CONDENSE AND PURIFY
WATER
SCRUBBER
WATER
46K (850)
CO_2 + CO VENT
400 OXYGEN
VAPORIZE AND OXIDIZE
COOL AND COLLECT
CHLORINE RECOVERY
WATER
10 NaOH
TREATMENT
MILLING
1000 TiO_2
PRODUCT
WATER
PURIFICATION AND COOLING TOWER WASTES
16(25) ORE
37(68) COKE
3(6) SiO_2
10(1) ZrO_2
25 $TiCl_4$
4 $CrCl_3$
2(380) Fe AS $FeCl_2$ + $FeCl_3$
6(2) V_2O_5
4(24) Al_2O_3
62 COPPER OR
10 H_2S OR
16 ORGANICS
130 HCl
WATER
SCRUB WATER
25 $TiCl_4$
50 HCl
WATER
EQUALIZATION AND SETTLING
Solids from Wastewater Treatment, to Landfill*
TITANIUM DIOXIDE PLANT WASTE
10 TiO_2
16 NaCl + Na_2SO_3
WATER
NONE
DISCHARGE

A PARENTHETICAL VALUES correspond to Ilmenite ore

FIGURE 4
TITANIUM DIOXIDE MANUFACTURE
BY THE CHLORIDE PROCESS USING RUTILE ORE OR ILMENITE ORE^A

*Potentially hazardous land destined waste

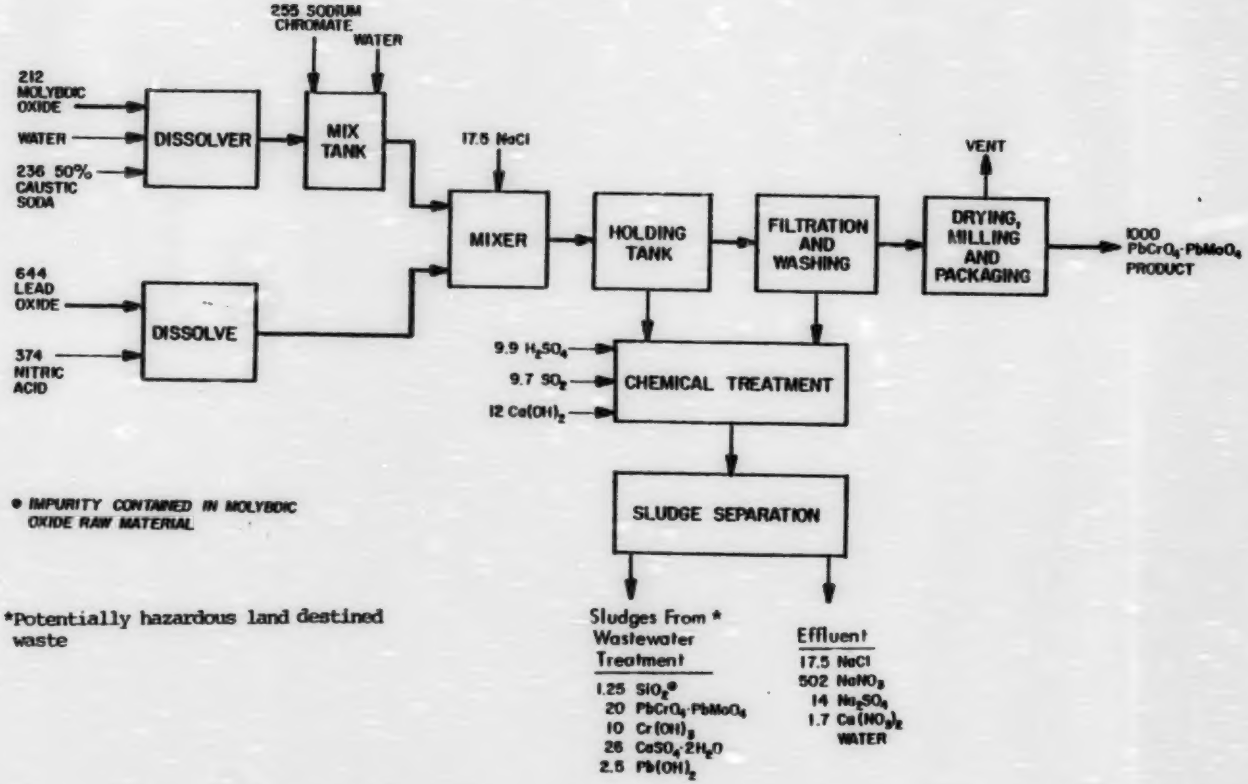

714 LEAD OXIDE
WATER
403 NITRIC ACID (OR ACETIC ACID)
DISSOLVING
263 50% NaOH
490 SODIUM DICHROMATE
DISSOLVING
MIXING AND DEVELOPMENT
FILTRATION AND WASHING
DRYING, MILLING AND PACKAGING
1000 $PbCrO_4$ PRODUCT
9.9 H_2SO_4
9.7 SO_2
12 $Ca(OH)_2$
WASTE TREATMENT
Sludges From* Wastewater Treatment
30 $PbCrO_4$
10.4 $Cr(OH)_3$
26.1 $CaSO_4 \cdot 2H_2O$
2.5 $Pb(OH)_2$
Effluent
544 $NaNO_3$*
14.3 Na_2SO_4*
1.7 $Ca(NO_3)_2$*
OR $Ca(OH)_2$
WATER

* VALUES WILL DIFFER DUE TO DIFFERENT REACTANTS USED TO MAKE DIFFERENT SHADES OF CHROME YELLOW

*Potentially hazardous land destined waste

FIGURE 5

CHROME YELLOW MANUFACTURE



212 MOLYBDIC OXIDE
WATER
236 50% CAUSTIC SODA
DISSOLVER
255 SODIUM CHROMATE
WATER
MIX TANK
644 LEAD OXIDE
374 NITRIC ACID
DISSOLVE
17.5 NaCl
MIXER
HOLDING TANK
FILTRATION AND WASHING
VENT
DRYING, MILLING AND PACKAGING
1000 PbCrO4·PbMoO4 PRODUCT
9.9 H2SO4
9.7 SO2
12 Ca(OH)2
CHEMICAL TREATMENT
SLUDGE SEPARATION
Sludges From * Wastewater Treatment
1.25 SiO2*
20 PbCrO4·PbMoO4
10 Cr(OH)3
26 CaSO4·2H2O
2.5 Pb(OH)2
Effluent
17.5 NaCl
502 NaNO3
14 Na2SO4
1.7 Ca(NO3)2
WATER

* IMPURITY CONTAINED IN MOLYBDIC OXIDE RAW MATERIAL

*Potentially hazardous land destined waste

FIGURE 6

MOLYBDATE CHROME ORANGE MANUFACTURE

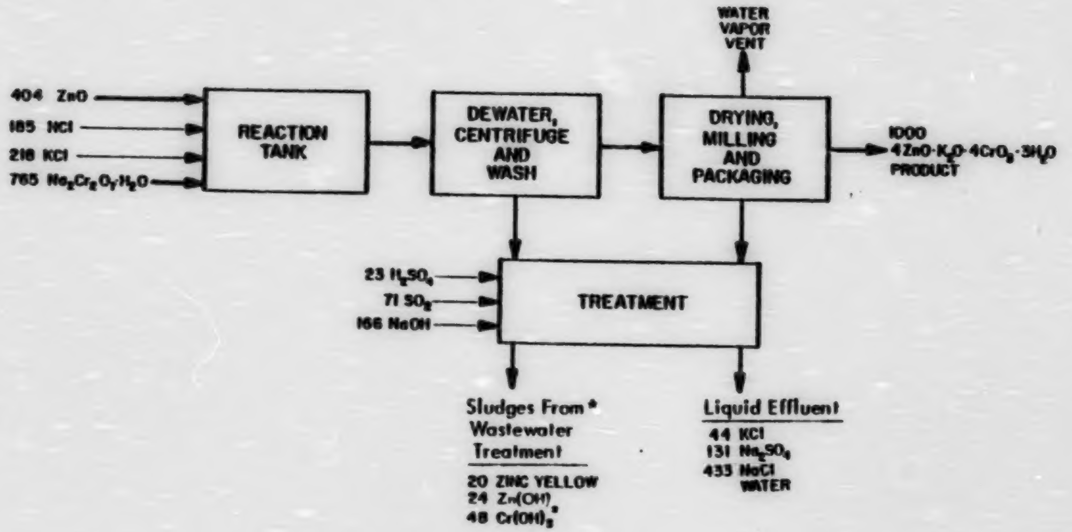

404 ZnO
185 HCl
218 KCl
765 $Na_2Cr_2O_7 \cdot H_2O$
REACTION TANK
DEWATER, CENTRIFUGE AND WASH
DRYING, MILLING AND PACKAGING
WATER VAPOR VENT
1000
$4ZnO \cdot K_2O \cdot 4CrO_3 \cdot 3H_2O$
PRODUCT
23 H_2SO_4
71 SO_2
166 NaOH
TREATMENT
Sludges From* Wastewater Treatment
20 ZINC YELLOW
24 $Zn(OH)_2$
48 $Cr(OH)_3$*
Liquid Effluent
44 KCl
131 Na_2SO_4
433 NaCl
WATER

FIGURE 7

ZINC YELLOW MANUFACTURE

*Potentially hazardous land destined waste

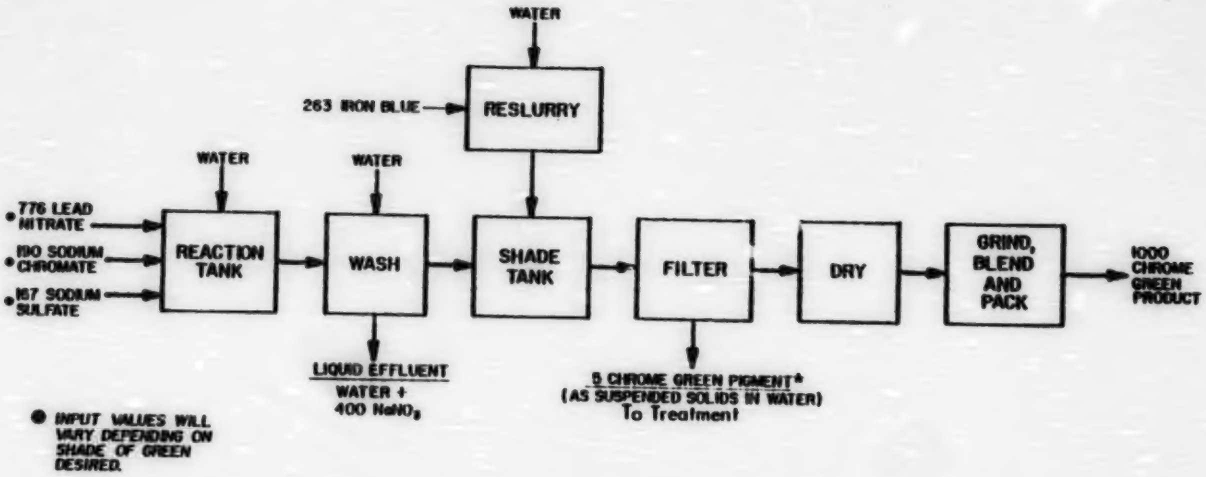

WATER
263 IRON BLUE
RESLURRY
WATER
WATER
776 LEAD NITRATE
190 SODIUM CHROMATE
167 SODIUM SULFATE
REACTION TANK
WASH
SHADE TANK
FILTER
DRY
GRIND, BLEND AND PACK
1000 CHROME GREEN PRODUCT
LIQUID EFFLUENT
WATER + 400 NaNO₃
5 CHROME GREEN PIGMENT*
(AS SUSPENDED SOLIDS IN WATER)
To Treatment
● INPUT VALUES WILL VARY DEPENDING ON SHADE OF GREEN DESIRED.

FIGURE 8
CHROME GREEN MANUFACTURE

*Treatment of this waste precipitates lead chromate, chromium (III) hydroxide, which is then land disposed as a sludge.

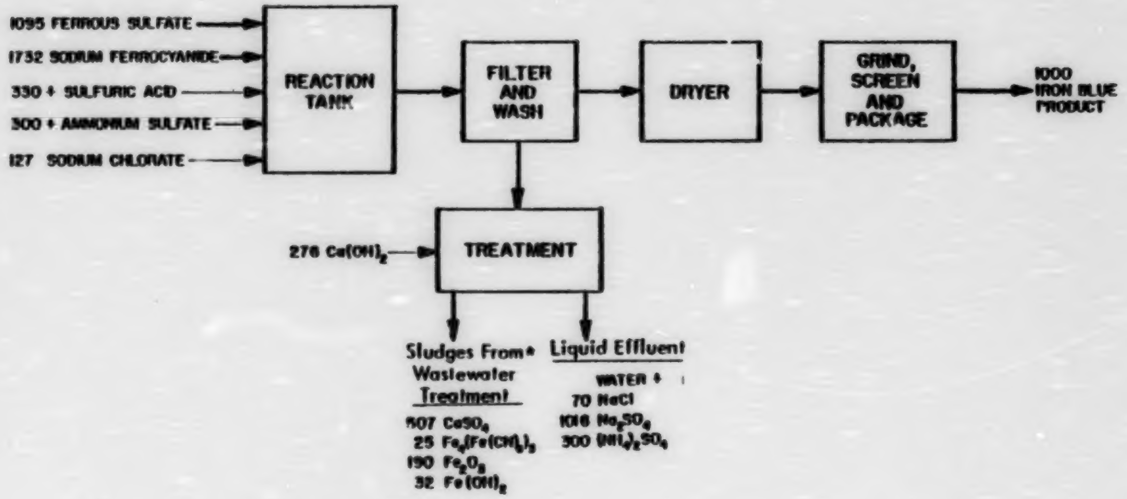

1095 FERROUS SULFATE
1732 SODIUM FERROCYANIDE
330 + SULFURIC ACID
300 + AMMONIUM SULFATE
127 SODIUM CHLORATE
REACTION TANK
FILTER AND WASH
DRYER
GRIND, SCREEN AND PACKAGE
1000 IRON BLUE PRODUCT
278 $Ca(OH)_2$
TREATMENT
Sludges From* Wastewater Treatment
507 $CaSO_4$
25 $Fe_4(Fe(CN)_6)_3$
190 Fe_2O_3
32 $Fe(OH)_2$
Liquid Effluent
WATER +
70 NaCl
1016 Na_2SO_4
300 $(NH_4)_2SO_4$

FIGURE 9

IRON BLUES MANUFACTURE

*Potentially hazardous land destined waste

3.3.5 Hydrofluoric Acid Manufacture

3.3.5.1 General Characterization of the Industry

There are 12 companies in 16 locations engaged in hydrofluoric acid manufacture. The total annual capacity of these plants is 369,000 kkg (407,000 tons). The typical hydrofluoric acid plant has a daily production rate of 64 kkg (70 tons).

3.3.5.2 Description of Potentially Hazardous Waste Streams

In the production of hydrofluoric acid, gypsum contaminated with hydrofluoric acid (HF), is generated as a waste. This material is generally sluiced with water from the reactors to the treatment ponds, where it is lime treated to convert free HF to calcium fluoride. The solids are then recovered and either stored on-site or landfilled. The land destined waste material consists mostly of gypsum with minor amounts of calcium fluoride and other impurities such as silica. Calcium fluoride is considered as the potentially hazardous component in this waste which is typically generated at a daily rate of 7 kkg (7.7 tons).

A process diagram for the manufacture of hydrofluoric acid is given in Figure 10.

3.3.6 Boric Acid Manufacture

3.3.6.1 General Characterization of the Industry

There are 3 companies engaged in boric acid manufacture. However, only one plant uses a feed stock which is contaminated with arsenic. A typical boric acid plant has a production rate of 110 kkg (121 tons) per day.

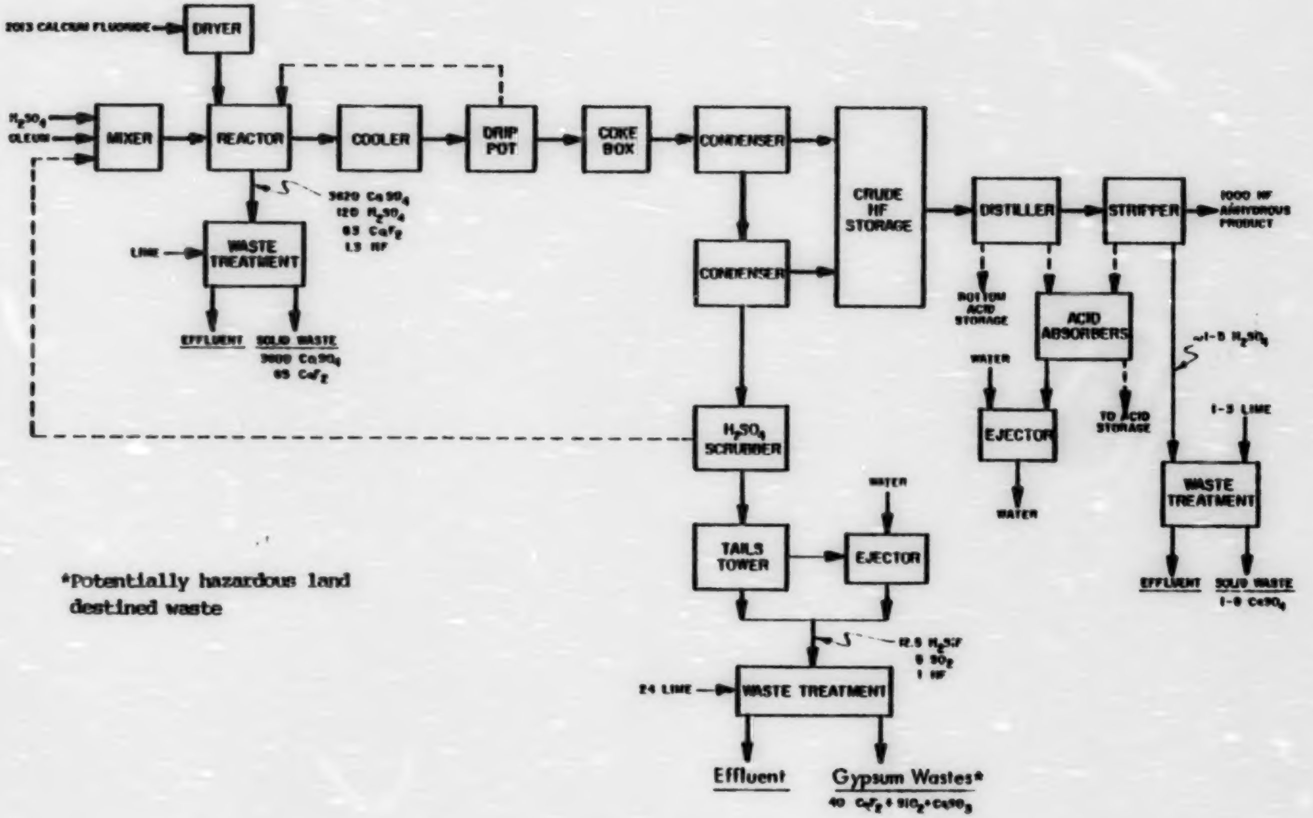
3.3.6.2 Description of Potentially Hazardous Waste Streams

A flow diagram for the manufacture of boric acid is given in Figure 11. The wastewaters at one plant contain small amounts of dissolved arsenic compounds. Treatment and filtration of this raw waste stream generate a filter cake containing arsenic as ferric arsenate. The quantity of filter cake varies from 0.2 to 0.5 kkg/day (0.22 to 0.55 tons/day) with an arsenic concentration of 100 to 1,000 ppm. Currently this waste is packed in drums and landfilled. Recommended treatment technique for this waste is encapsulation.

3.3.7 Aluminum Fluoride Manufacture

3.3.7.1 General Characterization of the Industry

There are 4 companies in the U.S. engaged in aluminum fluoride manufacture. The typical aluminum fluoride plant has a daily production rate of 145 kkg (160 tons).


2013 CALCIUM FLUORIDE
DRYER
H_2SO_4
OLEUM
MIXER
REACTOR
COOLER
DRIP POT
COKE BOX
CONDENSER
CONDENSER
CRUDE HF STORAGE
DISTILLER
STRIPPER
1000 HF ANHYDROUS PRODUCT
3620 $CaSO_4$
120 H_2SO_4
83 CaF_2
1.3 HF
LIME
WASTE TREATMENT
EFFLUENT
SOLID WASTE
3800 $CaSO_4$
85 CaF_2
BOTTOM ACID STORAGE
ACID ABSORBERS
WATER
EJECTOR
WATER
TO ACID STORAGE
~1-5 H_2SO_4
1-3 LIME
WASTE TREATMENT
EFFLUENT
SOLID WASTE
1-8 $CaSO_4$
H_2SO_4 SCRUBBER
TAILS TOWER
WATER
EJECTOR
12.5 H_2SiF
6 SO_2
1 HF
24 LIME
WASTE TREATMENT
Effluent
Gypsum Wastes*
40 $CaF_2 + SiO_2 + CaSO_3$

*Potentially hazardous land destined waste

FIGURE 10
HYDROFLUORIC ACID MANUFACTURE

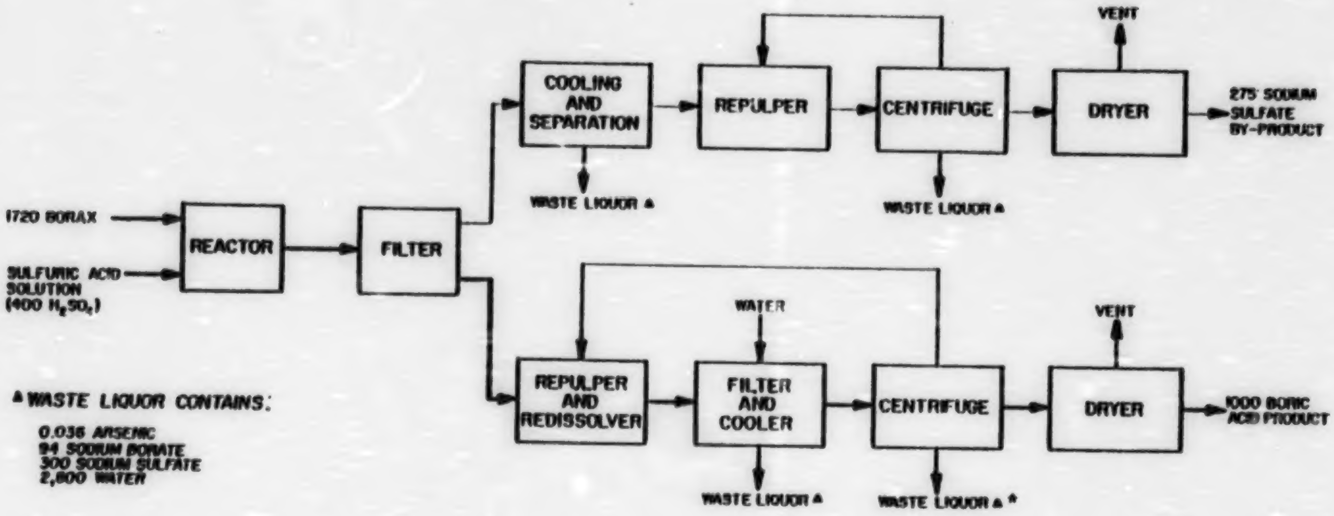

1720 BORAX
SULFURIC ACID SOLUTION (400 H_2SO_4)
REACTOR
FILTER
COOLING AND SEPARATION
WASTE LIQUOR ▲
REPULPER
CENTRIFUGE
WASTE LIQUOR ▲
VENT
DRYER
275 SODIUM SULFATE BY-PRODUCT
REPULPER AND REDISSOLVER
WATER
FILTER AND COOLER
WASTE LIQUOR ▲
CENTRIFUGE
WASTE LIQUOR ▲ *
VENT
DRYER
1000 BORIC ACID PRODUCT
▲ WASTE LIQUOR CONTAINS:
0.036 ARSENIC
94 SODIUM BORATE
300 SODIUM SULFATE
2,800 WATER

FIGURE 11
BORIC ACID MANUFACTURE

*Treatment and filtration of these waste streams generates a filter cake containing arsenic as ferric arsenate

3.3.7.2 Description of Potentially Hazardous Waste Streams

In the production of aluminum fluoride, treatment of scrubber liquor, used to scrub vent gases, generates a waste which is an impure calcium fluoride contaminated with gypsum, silica and other inert materials. The average quantity of calcium fluoride in the waste generated by the typical plant is 12 kkg (13.2 tons) per day.

Presently, this waste is either left in ponds, land stored or landfilled. A process diagram for the manufacture of aluminum fluoride is given in Figure 12.

3.3.8 Antimony Oxide Manufacture

There are six plants in the U.S. producing antimony oxide. At five facilities, process wastes containing residual antimony are further treated for resource recovery and these sites do not generate potentially hazardous solid waste material. One site, which was stockpiling antimony waste containing small quantities of arsenic sulfide, has recently changed their raw material and is currently using an impure antimony oxide which does not contain arsenic. Therefore, there are presently no potentially hazardous waste materials generated by this segment of the industry. Waste stream 12, antimony waste stockpile, has been eliminated from this study.

3.3.9 Sodium Silicofluoride Manufacture

3.3.9.1 General Characterization of the Industry

There are 4 companies engaged in the manufacture of sodium silicofluoride. The typical sodium silicofluoride plant has a production rate of 45 kkg (50 tons) per day.

3.3.9.2 Description of Potentially Hazardous Waste Streams

There are two processes by which sodium silicofluoride can be manufactured. In both cases, solid waste streams containing calcium fluoride are generated by wastewater treatment, which consists of precipitation with lime and settling or filtering of solids. Process flow diagrams are given in Figures 13 and 14.

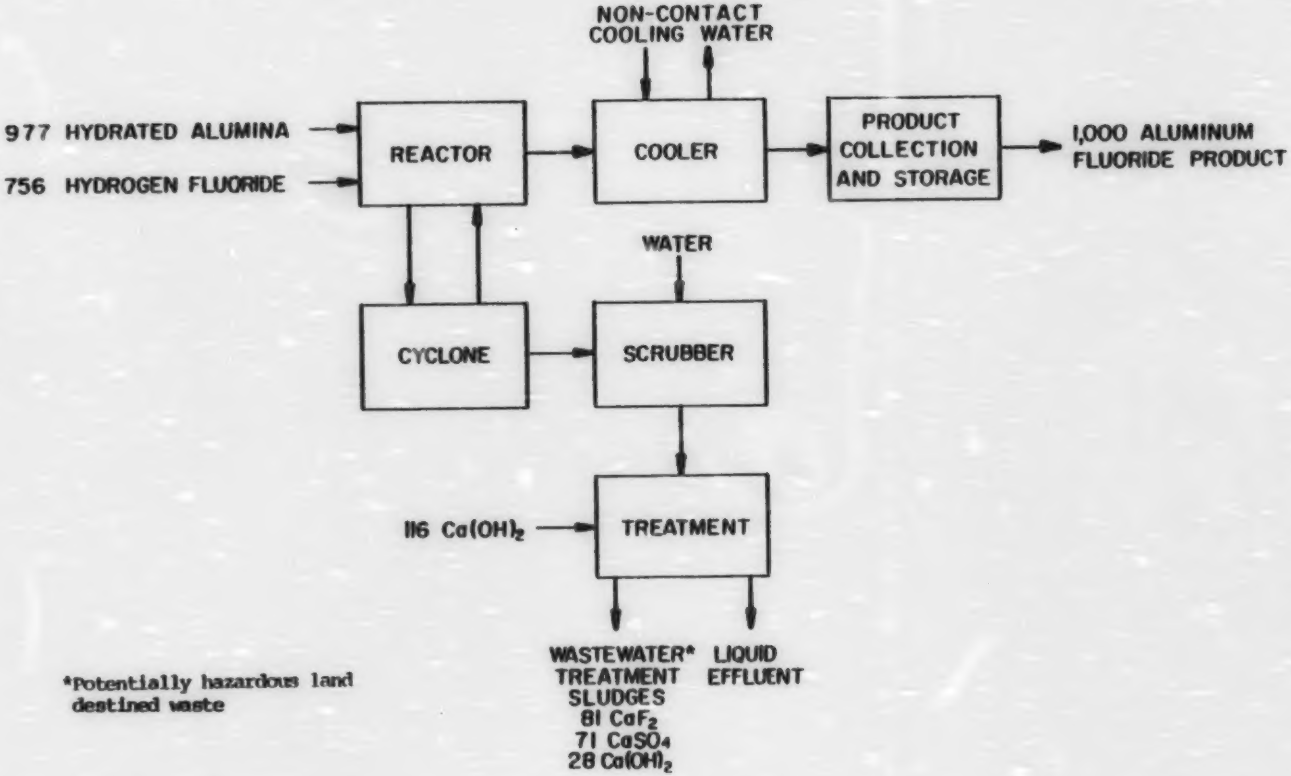
3.3.10 Chromate Manufacture

3.3.10.1 General Characterization of the Industry

There are six companies engaged in the manufacture of chromates. The typical plant produces 182 kkg (200 tons) per day.

3.3.10.2 Description of Potentially Hazardous Waste Streams

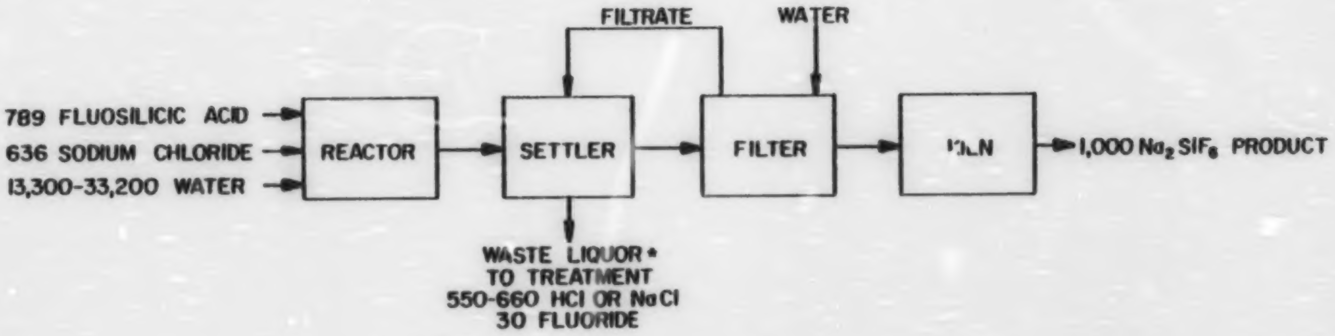
In the manufacture of chromates, the bulk of the wastes originates from the undigested portions of the ores used. Generally, these wastes are treated with reducing agents such as sulfur dioxide, sulfides or ferrous


NON-CONTACT COOLING WATER
977 HYDRATED ALUMINA
756 HYDROGEN FLUORIDE
REACTOR
COOLER
PRODUCT COLLECTION AND STORAGE
1,000 ALUMINUM FLUORIDE PRODUCT
WATER
CYCLONE
SCRUBBER
116 $Ca(OH)_2$
TREATMENT
WASTEWATER* TREATMENT SLUDGES
81 CaF_2
71 $CaSO_4$
28 $Ca(OH)_2$
LIQUID EFFLUENT

*Potentially hazardous land destined waste

FIGURE 12

ALUMINUM FLUORIDE MANUFACTURE



789 FLUOSILICIC ACID
636 SODIUM CHLORIDE
13,300-33,200 WATER
REACTOR
SETTLER
FILTRATE
WATER
FILTER
KILN
1,000 Na_2SiF_6 PRODUCT
WASTE LIQUOR*
TO TREATMENT
550-660 HCl OR NaCl
30 FLUORIDE

FIGURE 13

SODIUM SILICOFLUORIDE MANUFACTURE

*Treatment of this waste stream generates a sludge containing calcium fluoride

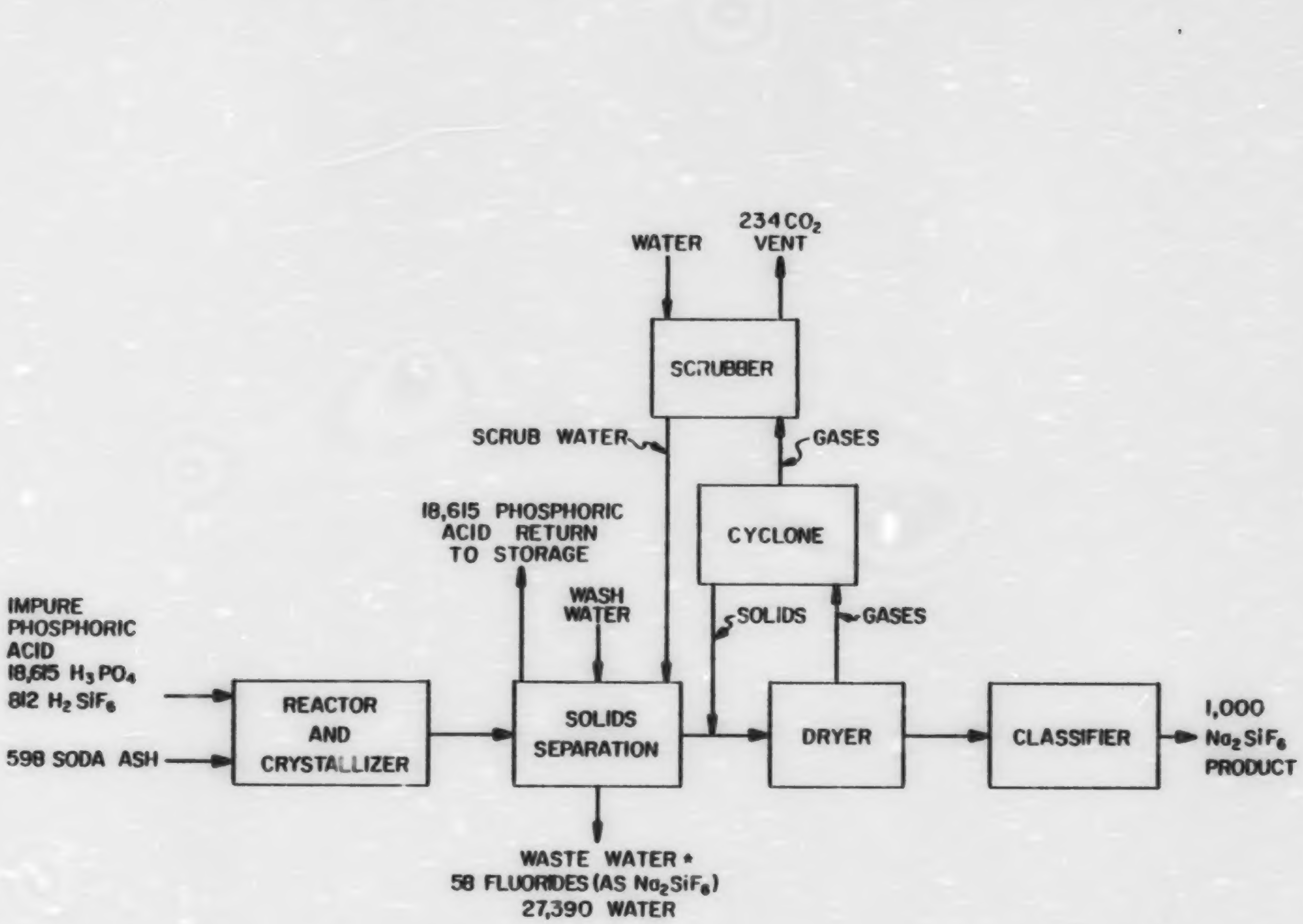

WATER
234 CO_2
VENT
SCRUBBER
SCRUB WATER
GASES
18,615 PHOSPHORIC
ACID RETURN
TO STORAGE
CYCLONE
IMPURE
PHOSPHORIC
ACID
18,615 H_3PO_4
812 H_2SiF_6
598 SODA ASH
WASH
WATER
SOLIDS
GASES
REACTOR
AND
CRYSTALLIZER
SOLIDS
SEPARATION
DRYER
CLASSIFIER
1,000
Na_2SiF_6
PRODUCT
WASTE WATER *
58 FLUORIDES (AS Na_2SiF_6)
27,390 WATER

FIGURE 14

SODIUM SILICOFLUORIDE MANUFACTURE
FROM AN IMPURE PHOSPHORIC ACID STREAM

*Treatment of this waste generates a sludge containing calcium fluoride chloride to reduce chromates to chromium III. The solid wastes generated are either ponded, stockpiled or disposed of in landfill operations. The constituents in these wastes, depending on treatment used, may include iron oxides, sulfides, chromium (III) oxides and hydroxides and small amounts of residual chromates.

The typical plant wastes produced daily, contains 0.025 kkg (0.0275 tons) of chromium hydroxide and 0.005 kkg (0.0055 tons) of chromate. Process flow diagrams for the manufacture of sodium dichromate and chromate are given in Figure 15.

3.3.11 Nickel Sulfate Manufacture

3.3.11.1 General Characterization of the Industry

There are 6 companies in 7 locations engaged in nickel sulfate manufacture. A typical nickel sulfate plant has a daily production rate of 9 kkg (10 tons).

3.3.11.2 Description of Potentially Hazardous Waste Streams

In the manufacture of nickel sulfate, solid wastes are produced from filtration of product solutions prior to evaporation and from the treatment of spent plating solutions. A typical nickel sulfate plant generates 1 kkg (1.1 tons) per day of solid waste containing about 0.7 kg (1.5 lb) of nickel hydroxide. A process diagram is given in Figure 16.

3.3.12 Phosphorus Manufacture, Furnace Process

3.3.12.1 General Characterization of the Industry

There are 6 companies in 9 locations that are engaged in the manufacture of phosphorus by the electric furnace process. The typical phosphorus plant has a production rate of 136 kkg (150 tons) per day.

3.3.12.2 Description of Potentially Hazardous Waste Streams

In the production of elemental phosphorus, there are two types of solid wastes generated:

(1) Treatment of scrubber wastewater generates sludges containing calcium fluoride along with other material (waste stream 16A). These solids are generally either pond stored or land disposed.

(2) Colloidal phosphorus settles from the water used to condense the phosphorus in the process. This waste is handled in two ways:

(a) the entire wastewater stream is impounded and the phosphorus settles out in the pond, where it is destroyed by the addition of lime. A slow reaction occurs in the presence of air to yield calcium hypophosphite.

(b) the "phossy water" stream (waste stream 16B) is treated with flocculants and the colloidal phosphorus is recovered and recycled. The treated "phossy water" stream is

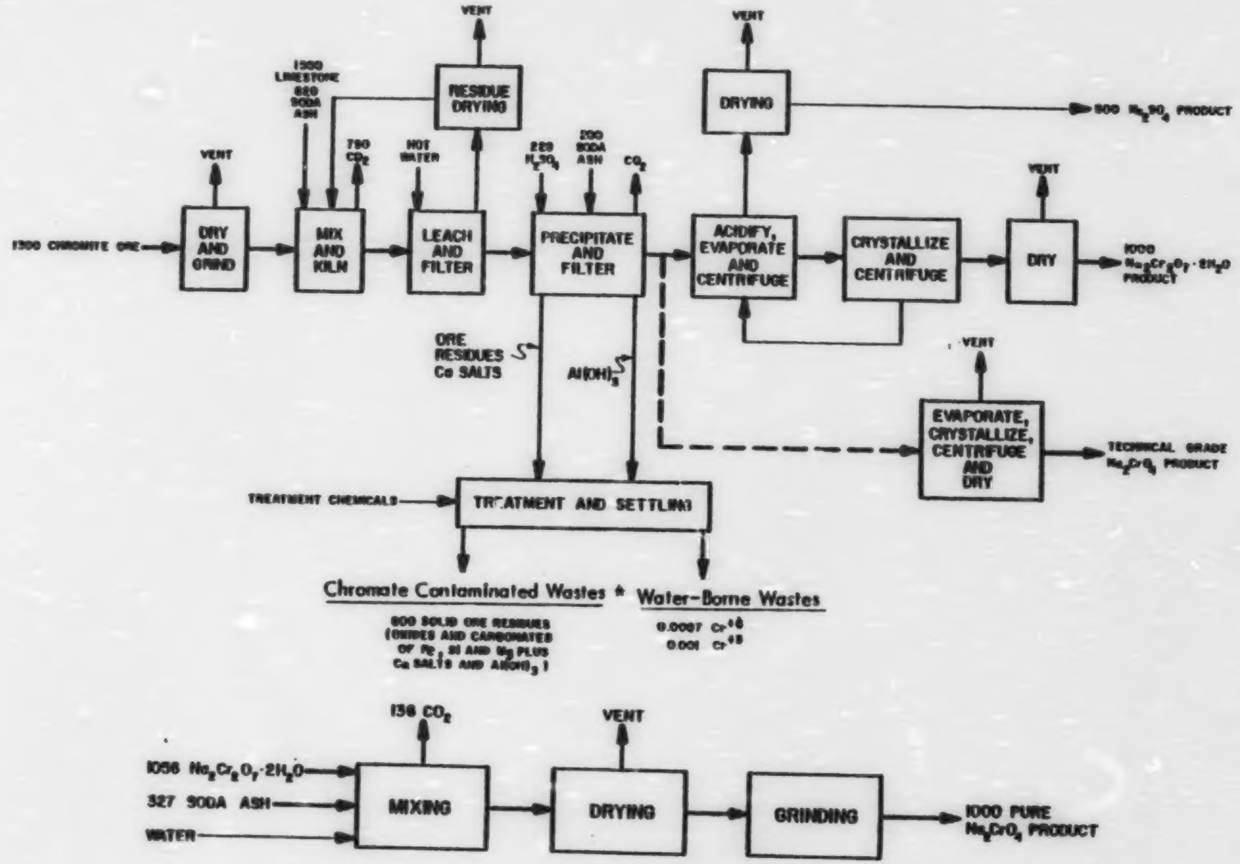

1300 CHROMITE ORE
VENT
DRY AND GRIND
1500 LIMESTONE
820 SODA ASH
790 CO2
MIX AND KILN
HOT WATER
LEACH AND FILTER
VENT
RESIDUE DRYING
220 H2SO4
200 SODA ASH
CO2
PRECIPITATE AND FILTER
ORE RESIDUES Ca SALTS
Al(OH)3
VENT
DRYING
800 Na2SO4 PRODUCT
ACIDIFY, EVAPORATE AND CENTRIFUGE
CRYSTALLIZE AND CENTRIFUGE
VENT
DRY
1000 Na2Cr2O7 · 2H2O PRODUCT
VENT
EVAPORATE, CRYSTALLIZE, CENTRIFUGE AND DRY
TECHNICAL GRADE Na2CrO4 PRODUCT
TREATMENT CHEMICALS
TREATMENT AND SETTLING
Chromate Contaminated Wastes *
800 SOLID ORE RESIDUES (OXIDES AND CARBONATES OF Fe, Si AND Mg PLUS Ca SALTS AND Al(OH)3)
Water-Borne Wastes
0.0007 Cr+6
0.001 Cr+3
1058 Na2Cr2O7 · 2H2O
327 SODA ASH
WATER
136 CO2
MIXING
VENT
DRYING
GRINDING
1000 PURE Na2CrO4 PRODUCT

FIGURE 15
SODIUM DICHROMATE AND CHROMATE MANUFACTURE

*Potentially hazardous land destined waste

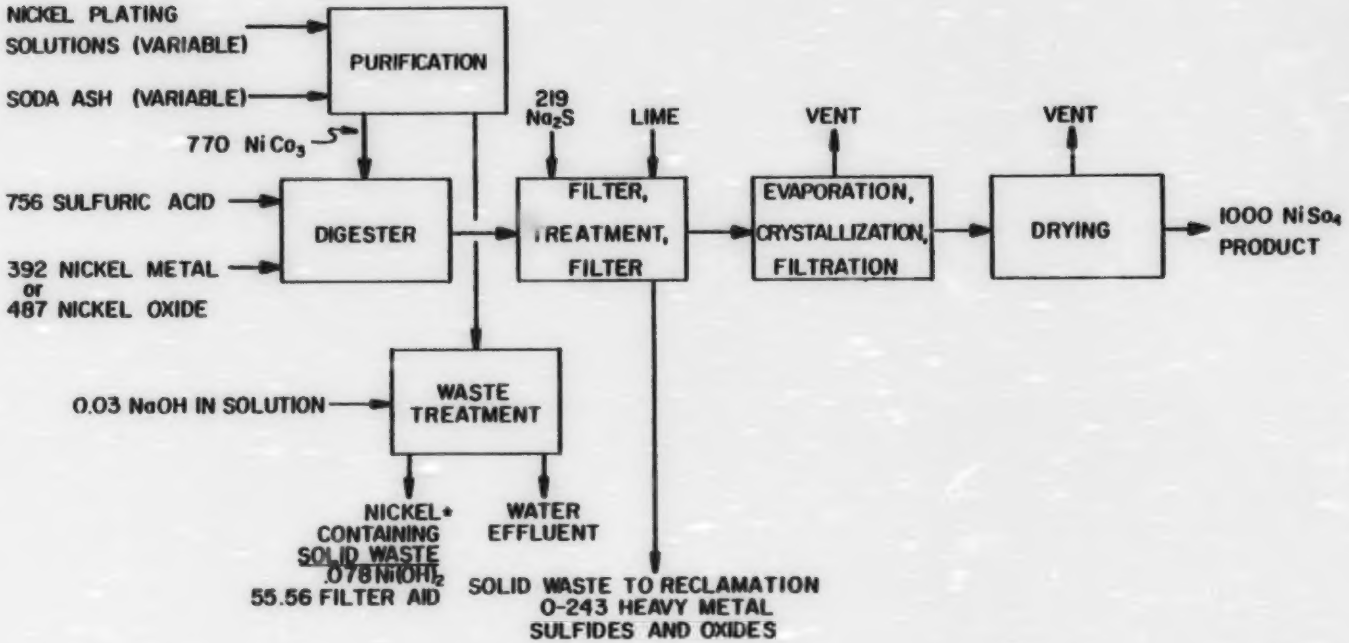

NICKEL PLATING SOLUTIONS (VARIABLE)
SODA ASH (VARIABLE)
PURIFICATION
770 $NiCo_3$
756 SULFURIC ACID
392 NICKEL METAL or 487 NICKEL OXIDE
DIGESTER
219 Na_2S
LIME
FILTER, TREATMENT, FILTER
VENT
EVAPORATION, CRYSTALLIZATION, FILTRATION
VENT
DRYING
1000 $NiSo_4$ PRODUCT
0.03 NaOH IN SOLUTION
WASTE TREATMENT
NICKEL* CONTAINING SOLID WASTE
.078 $Ni(OH)_2$
55.56 FILTER AID
WATER EFFLUENT
SOLID WASTE TO RECLAMATION
0-243 HEAVY METAL SULFIDES AND OXIDES

FIGURE 16

NICKEL SULFATE MANUFACTURE

*Potentially hazardous land destined waste

then impounded and residual phosphorus, which settled in the ponds, is either stored in the ponds or treated as in (a) above.

A process diagram is given in Figure 17.

3.3.13 Phosphorus Pentasulfide Manufacture

3.3.13.1 General Characterization of the Industry

There are three companies in seven locations engaged in the manufacture of phosphorus pentasulfide. A typical plant has an annual production rate of 55,000 kkg (60,600 tons).

3.3.13.2 Description of Potentially Hazardous Waste Streams

Phosphorus pentasulfide (P_2S_5) is made by reaction of phosphorus and sulfur. The potentially hazardous wastes from reactor water seals, still residues, and dust collection equipment are arsenic sulfide, phosphorus, phosphorus trisulfide, phosphorus pentasulfide dust, glassy phosphates, iron sulfide and carbon disulfide. In addition to the potential environmental hazards, the reactivity of this waste necessitates special handling. The P_2S_5 waste constituent results from equipment cleanout. A typical plant generates an annual average of 119 kkg (131 tons) of solid waste containing 3 kkg (3.3 tons) arsenic pentasulfide and 8 kkg (8.8 tons) phosphorus/phosphorus sulfides. A process diagram is given in Figure 18.

The only possible treatment for this stream is encapsulation because arsenic and phosphorus sulfides behave in a similar manner chemically and do not lend themselves to separation and recovery. Since encapsulation is not one of the 43 treatment processes under consideration, this waste stream will not be considered further in this report.

3.3.14 Phosphorus Trichloride Manufacture

3.3.14.1 General Characterization of the Industry

There are five companies in 6 locations engaged in the manufacture of phosphorus trichloride in the U.S. A typical plant has an annual production rate of 58,000 kkg (64,000 tons).

3.3.14.2 Description of Potentially Hazardous Waste Streams

In the manufacture of phosphorus trichloride, the product is generally purified by distillation. Still bottoms, which contain both unrecovered phosphorus trichloride and arsenic chlorides, are usually collected, treated to convert them to less reactive sulfides and are then drummed and buried at controlled landfill sites. A process diagram is given in Figure 19.

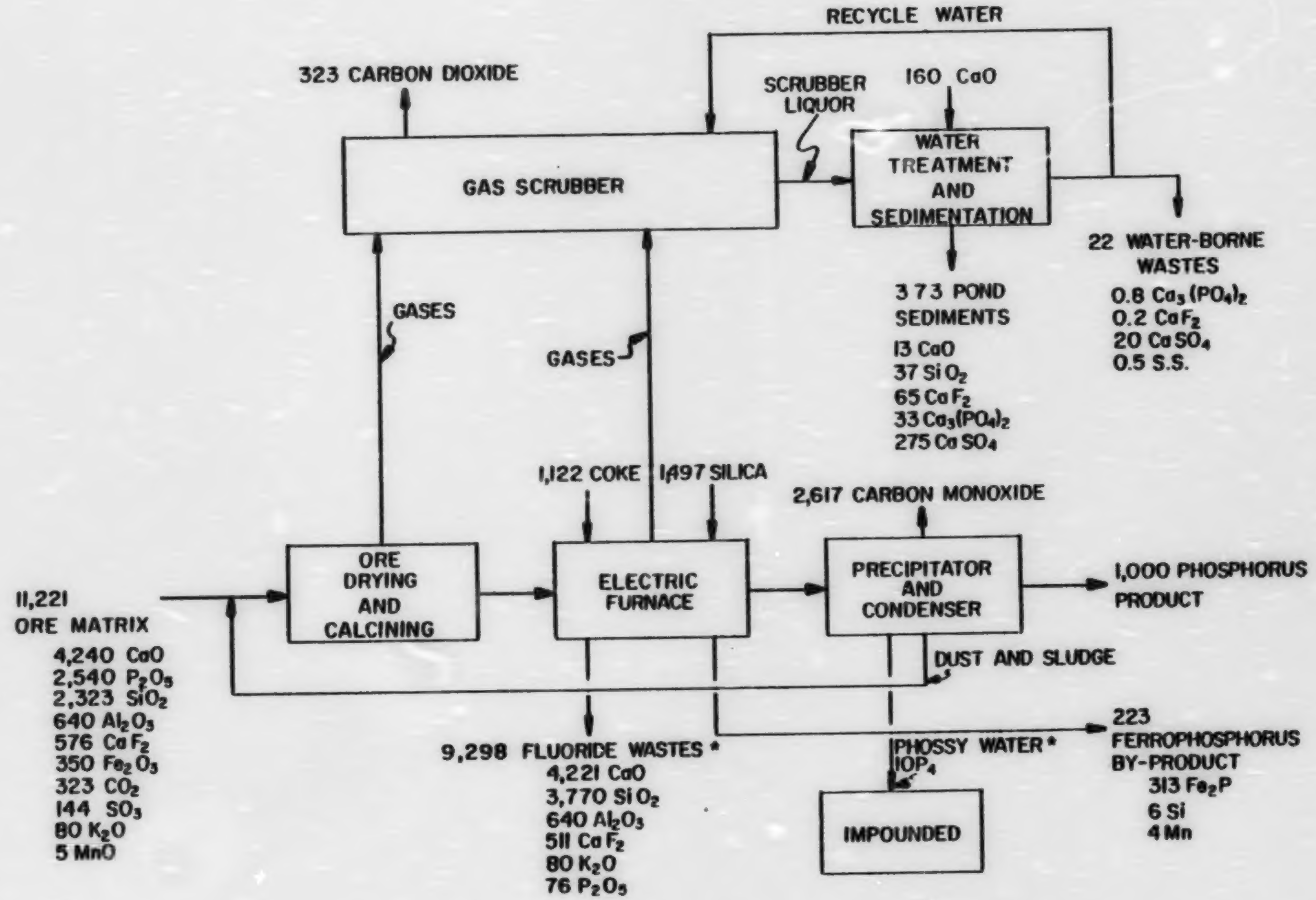

RECYCLE WATER
323 CARBON DIOXIDE
SCRUBBER LIQUOR
160 CaO
GAS SCRUBBER
WATER TREATMENT AND SEDIMENTATION
22 WATER-BORNE WASTES
0.8 $Ca_3(PO_4)_2$
0.2 CaF_2
20 $CaSO_4$
0.5 S.S.
GASES
GASES
3 7 3 POND SEDIMENTS
13 CaO
37 SiO_2
65 CaF_2
33 $Ca_3(PO_4)_2$
275 $CaSO_4$
1,122 COKE
1,497 SILICA
2,617 CARBON MONOXIDE
11,221 ORE MATRIX
4,240 CaO
2,540 P_2O_5
2,323 SiO_2
640 Al_2O_3
576 CaF_2
350 Fe_2O_3
323 CO_2
144 SO_3
80 K_2O
5 MnO
ORE DRYING AND CALCINING
ELECTRIC FURNACE
PRECIPITATOR AND CONDENSER
1,000 PHOSPHORUS PRODUCT
DUST AND SLUDGE
223 FERROPHOSPHORUS BY-PRODUCT
313 Fe_2P
6 Si
4 Mn
PHOSSY WATER*
10 P_4
IMPOUNDED
9,298 FLUORIDE WASTES*
4,221 CaO
3,770 SiO_2
640 Al_2O_3
511 CaF_2
80 K_2O
76 P_2O_5

FIGURE 17

PHOSPHORUS MANUFACTURE

*Potentially hazardous land destined waste

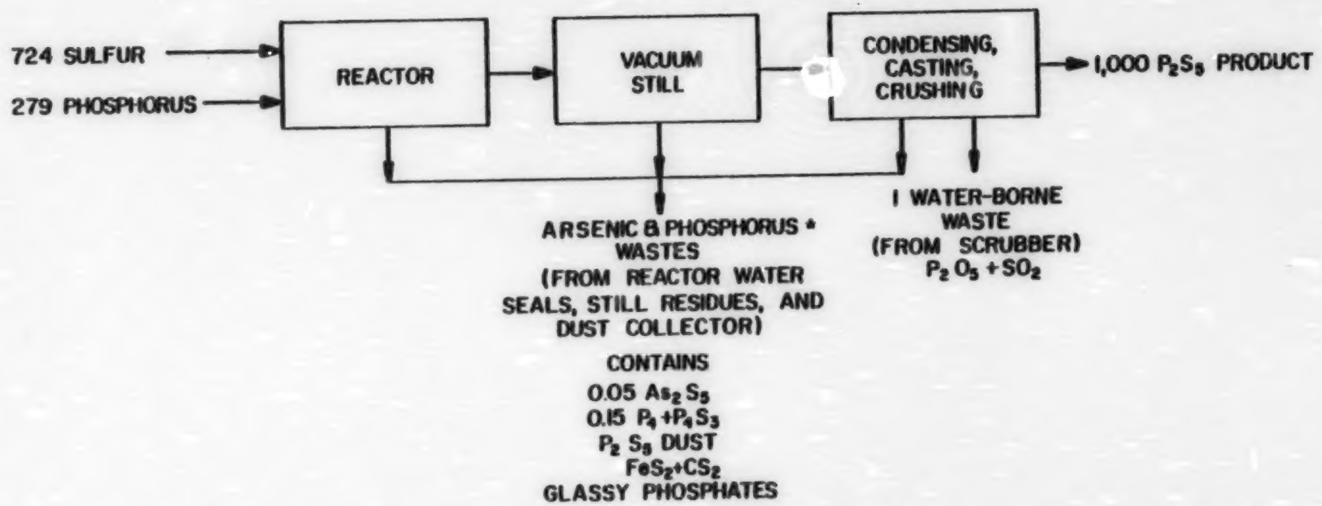

724 SULFUR
279 PHOSPHORUS
REACTOR
VACUUM STILL
CONDENSING, CASTING, CRUSHING
1,000 P_2S_5 PRODUCT
ARSENIC & PHOSPHORUS * WASTES
(FROM REACTOR WATER SEALS, STILL RESIDUES, AND DUST COLLECTOR)
CONTAINS
0.05 As_2S_5
0.15 $P_4+P_4S_3$
P_2S_5 DUST
FeS_2+CS_2
GLASSY PHOSPHATES
1 WATER-BORNE WASTE
(FROM SCRUBBER)
$P_2O_5+SO_2$

FIGURE 18

PHOSPHORUS PENTASULFIDE MANUFACTURE

*Potentially hazardous land destined waste

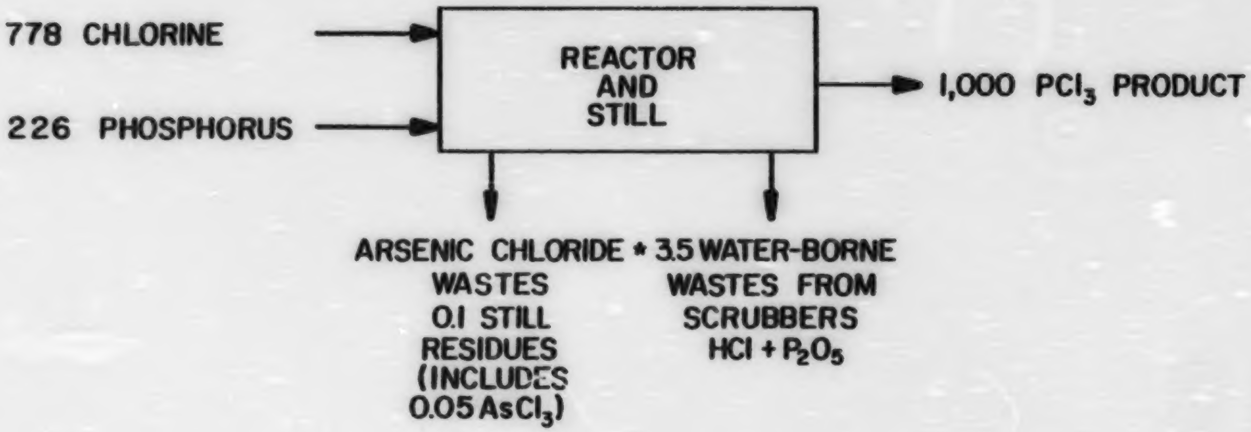

778 CHLORINE
226 PHOSPHORUS
REACTOR AND STILL
1,000 PCl_3 PRODUCT
ARSENIC CHLORIDE WASTES 0.1 STILL RESIDUES (INCLUDES 0.05 $AsCl_3$)
* 3.5 WATER-BORNE WASTES FROM SCRUBBERS $HCl + P_2O_5$

FIGURE 19

PHOSPHORUS TRICHLORIDE MANUFACTURE

*Potentially hazardous land destined waste

4.0 GENERAL DESCRIPTION OF TECHNOLOGIES SELECTED FOR TREATING INORGANIC WASTES

4.1 Introduction

Forty-three waste treatment technologies were examined under EPA Contract 68-01-2288. Of the 43 unit operations, only 23 were determined to be applicable to waste streams in the inorganic chemicals industry. Of these 23, only 9 were finally selected to be used for the waste streams under consideration. The approach used in selecting treatment alternatives involved the initial elimination of inappropriate processes and the selection of combinations of the remaining processes for further investigation. Using information contained in the draft report of Contract 68-01-2288, a matrix for comparing unit processes was prepared. This matrix, shown in Table 7, served as a general work sheet for expeditious screening and selecting of treatment possibilities. However, in all cases, the final choice of treatment processes for a particular waste stream was based on engineering judgment.

The following sections include brief descriptions of those technologies found appropriate for treating the potentially hazardous land destined waste streams in this industry.

4.1.1 Calcination

Calcination is a thermal decomposition process, generally operated at atmospheric pressure. It can be applied to aqueous slurries, sludges and tars to drive off volatiles and to produce a dry powder or calcined solid. Typical calciners include the open hearth, rotary kiln and fluidized bed types.

Calcination is particularly useful when a one-step process is required to deal with a complex waste, as it will destroy organic components and leave inorganic components in a more acceptable form for recovery or landfill. Calcination may be used to decompose salts or other compounds to form an oxide that will be more stable or reusable. Typical examples are the calcination of carbonates, hydroxides, sulfites, sulfides, sulfates and nitrates to the corresponding oxides with evolution of carbon dioxide, water, sulfur dioxide and nitrogen oxides, respectively.

4.1.2 Dissolution

Dissolution may be defined as the complete or partial transfer of one or more components in a solid to a liquid phase in contact with the solid. The reaction involves some degree of chemical transformation, such as solvation, ionization or oxidation. The solids are contacted by the reagent in a mixer and the insolubles are then separated. Heat may be applied to speed the process and provide increased solubility. Solids can be treated sequentially with different reagents to remove components selectively. The products are a wastewater stream that requires further treatment, and residual solids that may be suitable for disposal, reuse or further treatment.

TABLE 7

MATRIX FOR COMPARING UNIT PROCESSES

	KINDS OF WASTES TREATED			OUTPUT STREAM			POSSIBLE FOLLOW-ON STAGES	POLLUTION YIELDS				TREATMENT STUDY CATEGORY
Process	Physical Form	Chemical	Feed Requirement	Dry Solid	Sludge Slurry	Liquid/ Vapor*	Additional Treatment	H_2O	Solid	Air	Vented	V - Common in w.t. IV - not common in w.t. III - require develop. II - need research
Calcination	bulk solids	inorg., other an. & organics	tars or solids that can be volatilized	(1) oxide and/or other residue		(2) volatiles* (CO_2, NO_x, SO_x, HC)	(1) disposal or recovery	X	X	X		IV
	solid powders	other an. & inorg. organics										
	tars	organics	tars or solids that can be volatilized									
	sludges	organics	components that decompose by volatilization									
Carbon Adsorption	aqueous solution	other an., inorg. & org.	conc. <1% SS <50 ppm no oxidants	(1) absorbate, carbon		(2) purified H_2O	(1) chem. regen. (2) discharge					IV
Catalysis	liquid	inorg., org. and mixed		depends on reaction catalyzed				X		X		II
Centrifugation	slurry				(1) 2-15% solids	(2) 10-200 ppm TDS	decantation					V
Dissolution		primarily inorg.	tars, solids or solid powders that will dissolve in some reagent	(2) solid residue		(1) liquid sol. for further treatment				X		IV

TABLE 7

MATRIX FOR COMPARING UNIT PROCESSES (Continued)

	KINDS OF WASTES TREATED			OUTPUT STREAM			POSSIBLE FOLLOW-ON STAGES	POLLUTION YIELDS				TREATMENT STUDY CATEGORY
Process	Physical Form	Chemical	Feed Requirement	Dry Solid	Sludge Slurry	Liquid/ Vapor*	Additional Treatment	H_2O	Solid	Air	Vented	V - Common in w.t. IV - not common in w.t. III - require develop. II - need research
Distillation	liquid	organics	high organic conc.				(1) calcination, landfill		X			IV
	slurry	organics			(1) still bottom sludge	(2) purified liquid or solvent	(2) incineration					
	sludges	organics										
Electro-dialysis	aqueous solutions	inorg., heavy cat., an. & other an.	neutral or slightly acid; Fe & Mn <.3 ppm, Cu <400 ppm			(1) conc. stream, 100-500 ppm salts (2) dilute stream, 100-500 ppm TDS	(1) precip., recycle (2) unknown			X	X	IV
Electrolysis	aqueous solutions	inorg., org., an. & other an.	heavy metals <10%	(1) cathode reaction products (2) anode reaction products				X		X	X	III
Evaporation	slurry sludge liquid	inorganics & organics		(1) solid or	(1) sludge	(2) condensate	(1) calcination, landfill (2) distillation	X				IV
Filtration	slurry				(1) 5-50% solids	(2) 500-5,000 ppm TDS	(1) landfill, calcination (2) component separation		X	rare		V

TABLE 7

MATRIX FOR COMPARING UNIT PROCESSES (Continued)

	KINDS OF WASTES TREATED			OUTPUT STREAM			POSSIBLE FOLLOW-ON STAGES	POLLUTION YIELDS				TREATMENT STUDY CATEGORY
Process	**Physical Form**	**Chemical**	**Feed Requirement**	**Dry Solid**	**Sludge Slurry**	**Liquid Vapor***	**Additional Treatment**	**H_2O**	**Solid**	**Air**	**Vented**	V - Common in w.t. IV - not common in w.t. III - require develop. II - need research
Flotation	slurry		flotation particles in slurry			froth		X				III
Freeze Crystallization	aqueous solutions slurry, sludges	inorg, org. heavy met. cat., an. & other an.	TDS <10%		(1) sludge of conc. brine	(2) purified stream ~100 ppm TDS	(1) recovery, calcination (2) unknown		X	X		III
HGMS	slurry	heavy metal cat. & an.	magnetic or paramagnetic particles	particles adsorbed on magnetic filter		purified liquid stream		X				II
Hydrolysis	liquids slurries tars solid powders	organics organics organics inorg., org.	no conc. limits hydrolyzable component no conc. limits	mixture of products that may or may not be toxic				X	X			II - III
Ion exchange	aqueous solutions	heavy metal cat. & an., inorg. & org.	conc. <4,000 ppm low SS			(1) conc. solution of hazardous component (2) purified H_2O	(1) precipitation recycle electrolysis (2) discharge	little	little			IV

TABLE 7

MATRIX FOR COMPARING UNIT PROCESSES (Continued)

	KINDS OF WASTES TREATED			OUTPUT STREAM			POSSIBLE FOLLOW-ON STAGES	POLLUTION YIELDS				TREATMENT STUDY CATEGORY
Process	Physical Form	Chemical	Feed Requirement	Dry Solid	Sludge Slurry	Liquid/ Vapor*	Additional Treatment	H_2O	Solid	Air	Vented	V - Common in w.t. IV - not common in w.t. III - require develop. II - need research
Liquid Ion Exchange	aqueous solutions	inorg., heavy met., cat.& an.& other an.	no surfactants, SS <0.1%			same as above	same as above	X	little			IV
	sludges	heavy metal cat.& an.	solvent extractable inorg.component									
	solid powders	heavy metal cat. & an.										
Neutralization	liquids	inorg., org. and mixed			stream of altered pH			X		X		V
Oxidation	aqueous solution	other an. & orgs.	dilute solution of phenols, org. sulfur compounds, chlorinated hydrocarbons, etc.			CO_2*, H_2O & other oxidation products	depends on product stream comp.	X		X		III - IV
	slurries	other an. & orgs.										
	sludges	other an. & org.	cyanide sulfides, sulfites <1%									
Ozonation	aqueous solutions slurries sludges	other an. & organics inorganics organics organics	conc. 1%			CO_2*, H_2O & other ozonation products	depends on product stream comp.					IV
Precipitation	liquids	heavy met. cat.& an.	no conc. limits		(1) sludge	(2) liquid	(1) landfill, calcination (2) depends on residual conc.	X	X			V

TABLE 7

MATRIX FOR COMPARING UNIT PROCESSES (Continued)

	KINDS OF WASTES TREATED			OUTPUT STREAM			POSSIBLE FOLLOW-ON STAGES	POLLUTION YIELDS				TREATMENT STUDY CATEGORY
Process	Physical Form	Chemical	Feed Requirement	Dry Solid	Sludge Slurry	Liquid/ Vapor*	Additional Treatment	H_2O	Solid	Air	Vented	V - Common in w.t. IV - Not common in w.t. III - require develop. II - need research
Reduction	slurries	heavy metal cat. & an.	heavy metals <1%, controlled pH	heavy metals residual reducing agent			filtration	X	X	X		IV
	aqueous solutions sludge	heavy metal cat. & an. heavy metal cat. & an.										
Resin Adsorption	aqueous solutions	inorg. & org.	conc. <8% SS <50 ppm no oxidants	(1)absorbate, resin		(2) purified H_2O, <100 ppm organics	(1) solvent regeneration (2) unknown	X				IV
Reverse Osmosis	aqueous solution	inorg, heavy cat. & an.& other an.& org.	conc.>400 ppm controlled pH, low SS no strong oxidants			(1) conc. solution of hazardous component (2)purified solution TDS >5 ppm	(1) precip., recycle (2) unknown	X				IV
Ultra-filtration	liquids emulsions slurries	all inorg. & org. heavy cat. & an.&org. all			undesirable or hazardous components	(2) purified liquids			X			IV (for removal of organics from liquids and slurries)

In theory, dissolution may be applied to any solid containing a species of interest capable of being dissolved. Forms of solids that are acceptable include metallic wastes, dry powders, ashes and scrubber slurries.

4.1.3 Distillation

Distillation is the boiling of a liquid solution and condensation of the vapor for the purpose of separating solution components.

In the distillation process there are two phases, the liquid phase and the vapor phase. The components which are to be separated by distillation are present in both phases but in different concentrations. If there are only two components in the liquid, one concentrates in the condensed vapor (condensate) and the other in the residual liquid.

In the treatment of wastes, distillation is primarily used for the recovery of organics in liquid waste streams. It can also be used for separating certain inorganic chemicals from waste streams. Distillation is currently in use as part of the manufacturing process for certain inorganic chemicals such as hydrofluoric acid and phosphorus trichloride.

4.1.4 Electrolysis

Electrolysis refers to the reactions of oxidation or reduction that take place at the surface of conductive electrodes immersed in an electrolyte, under the influence of an applied potential. Electrolytic processes may be used in reclaiming heavy metals, including toxic metals from concentrated aqueous solution and for polishing dilute metallic wastewaters. They are not generally useful for viscous and tarry liquids.

4.1.5 Evaporation

Evaporation is the only method of general usefulness for the separation and recovery of dissolved solids in water. All others either involve merely concentration (reverse osmosis) or introduce contaminations to subsequent operations (demineralizer regenerants and chemical precipitations).

The evaporation process is well known and well established in the inorganic chemical industry. Separations, product purifications and solution concentrations are commonly accomplished by evaporative techniques.

On the other hand, evaporation is a relatively expensive operation. To evaporate one kilogram of water, approximately 550 kilogram-calories of energy is required and the capital cost for the evaporating equipment is not low. For these reasons, industrial use of evaporation in treating wastewater has been minimal.

Almost always, the treatment of wastewater streams by evaporation has utilized the principle of multi-effects to reduce the amount of steam or energy required. Thus, the theoretical limitation of carrying out the separation of a solute from its solvent is the minimum amount of work necessary to effect the particular change, that is the free energy change involved. A process can be made to operate with a real energy consumption not greatly exceeding this value. The greater the concentration of soluble salts, the greater is the free energy change for separation, but, even for concentrated solutions, the value is much lower than the 550 kg cal per kilogram value to evaporate water. Multi-effect evaporators use the heat content of the evaporated vapor stream from each preceding stage to efficiently (at low temperature difference) evaporate more vapor at the succeeding stages. Thus, the work available is used in a nearly reversible manner, and a lower energy requirement results. However, a large capital investment in heat transfer surface and pumps is required.

4.1.6 Filtration

Filtration is the most versatile method for removal of waterborne suspended solids. It is used for applications ranging from dewatering of sludges to removal of the last traces of suspended solids to give clear filtrates.

Filtration is accomplished by passing the wastewater stream through solids - retaining screens, cloths, or particulates such as sand, gravel, coal or diatomaceous earth using gravity, pressure or vacuum as the driving force.

Filtration equipment is of various designs including plate-and-frame, cartridge and candle, leaf, vacuum rotary, and sand or mixed media beds. All of these types are currently used in the treatment of waterborne wastes in the inorganic chemical industry.

4.1.7 High Gradient Magnetic Separation (HGMS)

HGMS is a technique for separating magnetic or weakly paramagnetic particles or other nonmagnetic materials (down to colloidal particle size) from slurries, sludges, and (after chemical treatment) from solutions. The feed stream is passed through a fine ferromagnetic filter which, when magnetized, collects the magnetic material. The filter is periodically cleaned, with the magnetic material recovered by a simple wash procedure. The removal of nonmagnetic material requires the feed to be treated with a magnetic seed (e.g., magnetite).

HGMS may be operated as either a cyclic or a continuous operation. Cyclic units are preferable when (1) the material being removed is a small percentage of the total volume passing through the system, and (2) high operating pressures are needed. Continuous operation may be preferable when (1) high operating pressures are not needed, and (2) the material being removed is a large percentage of the total volume passing through the system.

Current commercial applications of HGMS include beneficiation of hematite and the processing of molybdenum ore to remove iron impurities.

4.1.8 Neutralization and pH Control

Neutralization is the process by which acids and caustic wastes are reacted either with each other or with additional acid or caustic to form neutral salts. The resulting salts are usually less hazardous than either of the reactants. Also, the resultant salt may be insoluble and precipitate from the solution. Calcium salts derived from low cost limestone or lime are particular examples of limited solubility.

The control of pH may be equivalent to neutralization if the control point is at or close to pH 7. Chemical addition to waste streams may be designed, however, to maintain a pH level on either the acidic or basic side for purposes of controlling desired reactions or solubility.

4.1.9 Precipitation

The reaction of two soluble chemicals to produce insoluble or precipitated products is the basis for removing many undesired waterborne wastes. The use of this technique varies from lime treatments in order to precipitate sulfates, fluorides, hydroxides and carbonates to sodium or ferrous sulfide precipitations of copper, lead and other heavy metals. Precipitation reactions are particularly responsible for heavy suspended solids loads. Removal of these suspended solids is accomplished by means of settling ponds, clarifiers and thickeners, filters and centrifuges.

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5.0 TREATMENT PROCESSES SELECTED FOR A GIVEN WASTE STREAM

5.1 Introduction

Subsequent to the completion of the waste characterization and consultation phase of the study two facts became apparent: (1) it was recognized that the best technology for the treatment of several of the waste streams was either incineration or encapsulation, which were not covered under the "Treatment Study" and were considered to be out of the scope of work of this study; and (2) it was discovered that one of the potentially hazardous waste streams (stream 12) is no longer generated. Accordingly, upon EPA's approval, four of the original nineteen waste streams, identified as being potentially hazardous in an earlier study (EPA contract No. 68-01-2246), were eliminated from consideration in the alternative treatment study. These streams are:

- Stream 3, chlorinated hydrocarbons - diaphragm cell chlor-alkali plants.
- Stream 10, arsenic-containing sludges-boric acid manufacture.
- Stream 12, antimony waste stockpile-antimony manufacture.
- Stream 17, arsenic and phosphorus wastes - phosphorus pentasulfide manufacture.

Supporting rationale for the elimination of these streams is offered below:

Chlorinated Hydrocarbons

The chlorinated hydrocarbon waste stream from diaphragm cell chlor-alkali plants is characterized by the industry as a variable waste stream ranging in consistency from oily to tar-like material. This waste arises from the reaction of chlorine with organic material in the carbon anode and elsewhere in the cell. The composition of this stream varies within a given operational day depending on the condition of the cell anode or the operating condition of the chlorine purification system where the waste collects.

The contractor's consensus is that since this waste is a mixed and poorly defined material, it is not amenable to resource recovery by any of the 43 processes in the "Treatment Study". The best available technology to treat this stream, which is currently practiced by at least five plants, is destruction by incineration. There are a maximum of 30 plants that generate chlorinated hydrocarbons averaging 70 kkg/yr per plant. This quantity of waste is not large enough to warrant installation of individual incinerators, therefore, contract incineration is recommended in an incinerator equipped with a scrubber for the combustion gases.

Additionally, the quantity of this waste can be reduced by replacing the graphite anodes by coated metal anodes (dimensionally stable anodes, DSA). This waste has been minimized at mercury cell plants by use of DSA. Conversion is proceeding at a much slower pace at diaphragm cell plants.

Arsenic Bearing Wastes from Boric Acid Manufacturing

This waste stream is currently produced as a filter cake containing arsenic in one of its least soluble forms (as ferric arsenate). There is only one plant in the U.S. generating this waste. The quantity of this waste varies from 0.2 to 0.5 kkg/day and the waste has an arsenic concentration of 100 to 1,000 ppm.

The contractor's consensus is that the only possible treatment for this waste stream is encapsulation. Ferric arsenate is in trace quantities co-mixed with a relatively large volume of filter aid. The filter aid adsorbs the arsenate and minimizes separation.

Antimony Waste Stockpile

This waste stream is no longer generated. Contact with the sole producer in the U.S. on September 14, 1976, revealed that the manufacturer had changed their raw material and was no longer processing antimony sulfide which contained the hazardous component [arsenic sulfide (As_2S_3)]. The current feed stock is an impure antimony oxide that does not contain As_2S_3.

Arsenic and Phosphorus Wastes from Phosphorus Pentasulfide Manufacture

This waste is currently being produced as dry residue by seven U.S. plants. The quantity of this waste is an average of 119 kkg/yr per plant, containing 108 kkg/yr of glassy phosphate and iron sulfide, 3 kkg/yr of arsenic pentasulfide and 8 kkg/yr of phosphorus/phosphorus sulfide.

The contractor's consensus is that the only possible treatment for this waste stream is encapsulation. Arsenic sulfide and phosphorus sulfide behave chemically in a similar manner and do not lend themselves to separation and recovery.

A process consisting of encapsulation of this waste stream in butadiene resin, molding the resulting product in individual blocks and coating the blocks with polyethylene, was recommended for this waste stream. However, this process was not approved by EPA since encapsulation was not among the processes to be considered in our study.

The "Butadiene Encapsulation" process, developed by TRW under a contract with EPA Cincinnati, is considered by the contractor to be the best technology for treating this waste stream.

No further discussions are offered in this section on the above four waste streams. The following sections include process analysis information and waste data of the treatment schemes selected for the remaining fifteen waste streams.

5.1.1 Waste Streams 1 and 2, Brine Purification Mud and Mercury Wastes from Treatment and Cleaning - Mercury Cell Process, Chlor-Alkali Manufacture

Two resource recovery processes were selected to treat the two waste streams generated by the mercury cell process. These are:

(1) recovery of mercury by sodium hypochlorite dissolution and (2) recovery of mercury by roasting of the sludges. Both schemes process the combination of the two waste streams 1 and 2. Both are known and demonstrated technologies.

5.1.1.1 Treatment Scheme 1 - Recovery of Mercury by Sodium Hypochlorite Dissolution

5.1.1.1.1 Process Description and Material Balance

The dissolution of the brine purification mud (stream 1) and the dewatering and separation of the solids are operated in a continuous manner. The incorporation of the filtrate from this operation with the wastewater treatment sludges (stream 2) and subsequent treatment for mercury recovery are conducted in a batch operation.

The brine purification mud, containing about 23 weight percent solids, is acidified with spent sulfuric acid (70 percent) to a pH level of approximately 2 to promote the growth and precipitation of calcium carbonate crystals. The acidified waste stream is next treated with sodium hypochlorite in an agitated tank to a pH level of 6 to 7 to dissolve the mercury chloride and elemental mercury in the waste sludge. The product from the sodium hypochlorite dissolution tank is vacuum filtered to separate the waste solids. The filtrate is allowed to settle in a clarifier and is then collected in a receiver for subsequent mercury recovery. The filter cake is combined with the clarifier underflow, monitored and landfilled. This waste sludge contains less than 40 ppm of mercury on a dry basis (about 15 ppm, wet basis).

All subsequent downstream operations are run in a batch manner. The clarified filtrate from the receiver is combined with other mercury-containing waste streams (stream 2) generated at the plant and treated with sodium bisulfite ($NaHSO_3$), sulfuric acid (H_2SO_4) and sodium hydrosulfide (NaSH), respectively, in a 16-hour cycle batch reactor for mercury sulfide precipitation. The purpose of $NaHSO_3$ addition is to destroy residual chlorine in the wastewaters. The wastewater is then acidified to a pH level to 3 to 3.5 and treated with NaSH to effect the precipitation of mercury sulfide. The effluent from the treatment tank is passed through a horizontal leaf filter in a batch manner (ten batches per week). Once a week, the filter leaves are pulled out and the mercury sulfide filter cake is placed in the sodium hypochlorite redissolution tank where it is reacted with sodium hypochlorite to a pH level of 8 to 9. The duration of this operation is two hours, after which the resulting solution, containing sodium oxychloride mercury ions, is returned to the main plant brine circuit.

The filtrate from the leaf filter is sent to a neutralization tank where the pH is adjusted to a level of 7 to 9 by the addition of caustic. The effluent from this tank is monitored for mercury (less than 0.045 kg of mercury/day) prior to discharge. Wastewater with too high a mercury content is returned to the treatment tank for processing.

The chlorine vapors from the vacuum filter circuit and hydrogen sulfide vapors generated from the treatment tank are pulled through a caustic scrubber prior to venting. The scrubbing liquor is recirculated and replaced once a week. The spent caustic is returned to the brine purification mud sump.

Figure 20 shows a detailed flow sheet and material balance for a treatment plant to process waste sludges (streams 1 and 2) generated by a typical 250 kkg/day mercury cell chlor-alkali plant. Material balances and recovery values shown are prorated from a 154 kkg/day existing operation. The only adaptation made throughout the process is the assumption that the wastewater treatment sludges (stream 2) instead of the raw wastewater will be combined with the filtrate from the vacuum filter operation prior to $NaHSO_3$/NaSH treatment and mercury sulfide precipitation. The existing plant has no separate wastewater treatment system. Plants which do have a sulfide treatment system and generate wastewater treatment sludges (stream 2) could combine this sludge with waste stream 1 prior to sulfide precipitation. In stream 2, at most plants, mercury is in the sulfide form and can be readily processed for recovery.

5.1.1.1.2 Applications to Date

a. Full-scale Treatment Installation

This treatment process is currently being used by BASF Wyandotte, Inc. in Port Edwards, Wisconsin. The process installation was completed in late 1973. The plant has been operating essentially trouble free since start-up. The treatment plant handles brine purification mud and other mercury-containing wastewaters from cell room operation from a 154 kkg/day chlor-alkali mercury cell operation. Mr. Brian Johnson is the key contact at the plant.

Additionally, the sodium hypochlorite extraction of mercury from brine sludges has been used by four chlor-alkali plants in Japan. The Japanese process, which is similar to the BASF method, has been marketed in the United States since 1970 by Crawford & Russell, who claim the process will remove more than 85 percent of the mercury from the brine sludge.[24]

In a more recent publication, Crawford & Russell claimed a reduction of mercury in the dry sludge from 50-4,000 ppm to 0.1 ppm using the sodium hypochlorite leaching process with pH adjustment.[90]

b. Laboratory and Pilot Plant Operations

The initial work on extracting mercury from brine sludge was performed using sodium hypochlorite. This method was known to remove mercury as early as 1924 from Glaeser's work.[30] Extensive work has been done on sodium hypochlorite leaching of mercury from low grade ores by Parks,[68,69] Town[86] and others. Although Parks achieved good recovery (96.4 per cent) there still was 10 ppm mercury left in the residue. Tokana[85] found that multi-staging the extraction process could increase the mercury recovery to 99 percent with eight stages.

Laboratory work based on sodium hypochlorite leaching of mercury has also been conducted by Georgia-Pacific Corporation in Bellingham, Washington. Experiments involved test runs with one liter of brine sludge to 250 ml of sodium hypochlorite. The maximum mercury recovery achieved during these runs in one stage has been reported to be 86 percent.[90] Several experiments were subsequently conducted using multi-stage leaching systems. It was concluded that, due to the difficulty and expense required to separate the liquid

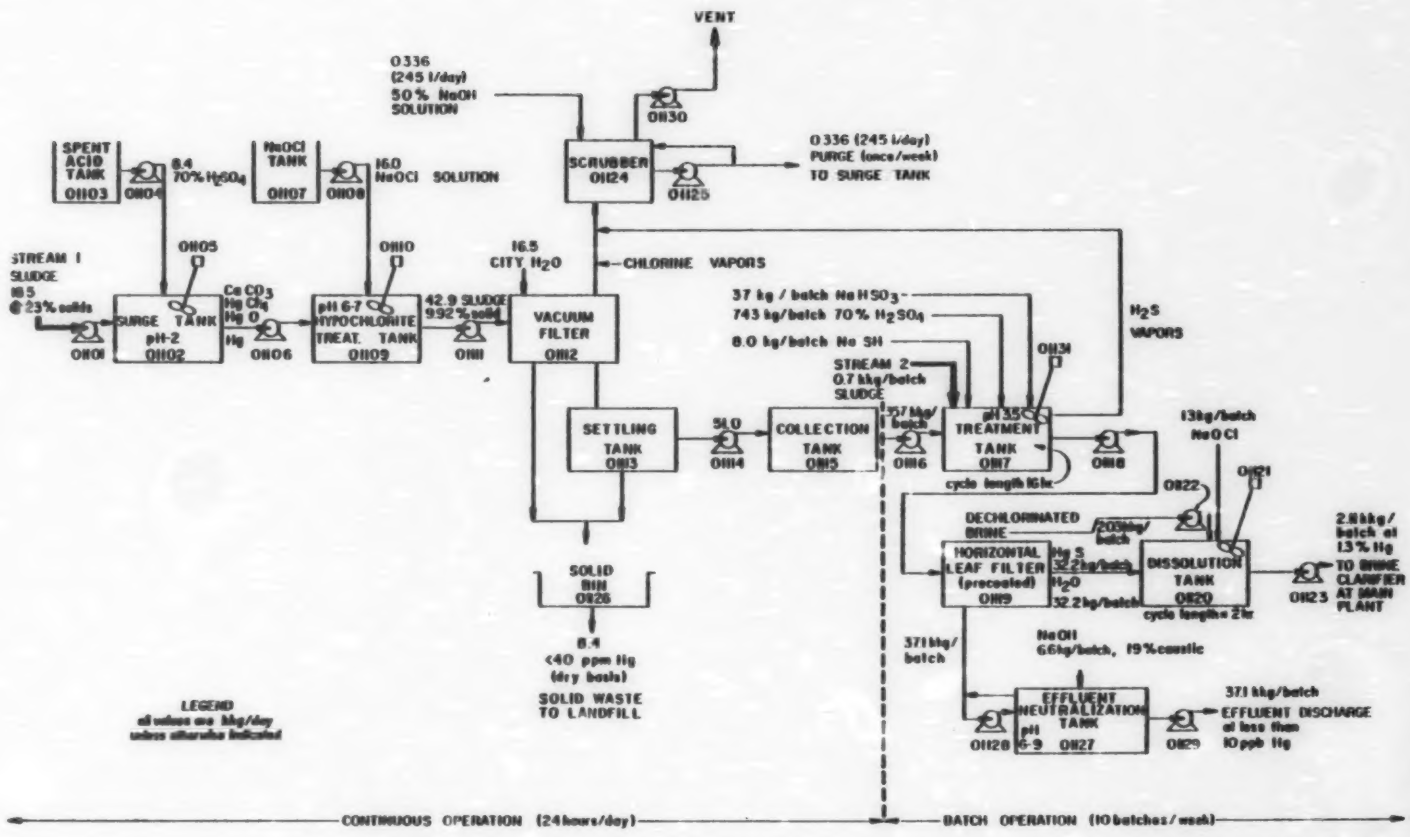
VENT
0336
(245 l/day)
50% NaOH
SOLUTION
0336 (245 l/day)
PURGE (once/week)
TO SURGE TANK
SPENT
ACID
TANK
01103
01104
8.4
70% H2SO4
NaOCl
TANK
01107
01108
16.0
NaOCl SOLUTION
SCRUBBER
01124
01130
01125
STREAM 1
SLUDGE
18.5
@ 23% solids
01101
01105
SURGE TANK
pH-2
01102
CaCO3
HgCl4
HgO
Hg
01106
01110
pH 6-7
HYPOCHLORITE
TREAT. TANK
01109
42.9 SLUDGE
9.92% solids
01111
16.5
CITY H2O
VACUUM
FILTER
01112
←CHLORINE VAPORS
SETTLING
TANK
01113
51.0
01114
COLLECTION
TANK
01115
37 kg / batch NaHSO3
743 kg/batch 70% H2SO4
8.0 kg/batch Na SH
STREAM 2
0.7 kkg/batch
SLUDGE
357 kkg/batch
01116
01131
pH 3.5
TREATMENT
TANK
01117
cycle length 16 hr
01118
H2S
VAPORS
13kg/batch
NaOCl
01122
01121
DECHLORINATED
BRINE
203kkg/batch
HORIZONTAL
LEAF FILTER
(precoated)
01119
HgS
32.2kg/batch
H2O
32.2kg/batch
DISSOLUTION
TANK
01120
cycle length = 2 hr
01123
2.8kkg/
batch at
1.3% Hg
TO BRINE
CLARIFIER
AT MAIN
PLANT
SOLID
BIN
01126
8.4
<40 ppm Hg
(dry basis)
SOLID WASTE
TO LANDFILL
371 kkg/
batch
NaOH
6.6kg/batch, 19% caustic
EFFLUENT
NEUTRALIZATION
TANK
pH
6-9
01127
01128
01129
371 kkg/batch
EFFLUENT DISCHARGE
of less than
10 ppb Hg
LEGEND
all values are kkg/day
unless otherwise indicated
CONTINUOUS OPERATION (24 hours/day)
BATCH OPERATION (10 batches/week)

FIGURE 20 - MERCURY RECOVERY BY SODIUM HYPOCHLORITE DISSOLUTION (system 01100)

from the fine solids at each stage, a practical system may be restricted to a maximum of two-stage operation, with a mercury recovery of less than 90 percent.

Laboratory work performed by BASF Wyandotte has indicated that the key to the success of high level mercury recovery by sodium hypochlorite leaching is control of brine mud particle size and pH adjustment during various steps of the treatment process.

c. Pilot or Full-scale Operations Treating Similar Wastes

None known.

5.1.1.1.3 Benefits and Environmental Consequences

a. Benefit Analysis Information

The benefits resulting from sodium hypochlorite treatment of mercury bearing wastes (streams 1 & 2) from mercury cell chlor-alkali plants are:

(1) mercury recovery,

(2) solid waste reduction and

(3) solid waste detoxification.

For the typical plant, this system achieves mercury recovery at a rate of 39.2 kg/day. Using a price of $9.10 per kilogram of mercury purchased, this treatment process would incur an annual resource recovery value of $130,000 or $1.42 per metric ton of chlorine produced.

The treatment plant will also achieve an annual cost savings of $7,885 resulting from the volume reduction of land destined wastes (excluding treatment process costs). The quantity of the solid waste generated by the treatment plant will be 8.4 kkg/day as compared to the original 12.0 kkg/day solid waste destined to landfills. Additionally, the solid waste will be essentially detoxified. The original waste contains 8,420 ppm mercury on a dry basis. The treated waste will contain less than 40 ppm mercury on a dry basis. This corresponds to a 99.5% reduction in mercury content of the land destined solid waste.

A summary of the benefits achieved by this process is shown in column 1 of Table 8 which summarizes the benefit analyses for all treatment processes considered in this study.

b. Environmental Impact

There are air emissions, waterborne waste and land destined wastes generated by this treatment process. However, in general, this process presents a minimal threat to the environment and personnel safety. Nearly all chemicals used in this treatment process are readily available onsite such as sodium hypochlorite which is generated by the main process as a result of chlorine tail gas scrubbing.

TABLE 8
BENEFIT ANALYSIS[1]

Columns	1	2	3	4	5	6	7	8
Waste[3] Stream	1&2	1&2	4	5	6	7	8	8
Treatment System	01100	01200	04100	05100	06100	07100	08100	08200
Industry Category	Chlorine Manufacturing				Sodium & Chlorine Mfg.	Titanium Dioxide Chloride Process	Chrome Color & Inorganic Pigment	Chrome Color & Inorganic Pigment
	Mercury Cell Plants		Diaphragm Cell		Down's Cell			
Treatment Process	Sodium Hypochorite Dissolution	Mercury Roasting	Asbestos Fusion	Lead Recovery by smelting	Electrolysis	Calcination	Calcination	Evaporation & Asphalting
Material Recovered	Mercury as a complex	Elemental Mercury	—	Elemental lead	Sodium & Cell Bath	—	—	—
Amount Recovered kkg/Day	0.0392	0.0399	—	0.125	2.86 Na 0.62 $CaCl_2$ - NaCl	—	—	—
Resource Recovery Value $/Yr.	130,000	132,300	—	10,725	328,900	—	—	—
Resource Recovery Value $/kkg product	1.42	1.45	—	0.065	6.44	—	—	—
Savings in Waste Volume Reduction $/yr. @ $6/kkg.	7,885	13,820	—	8,860	231,000	1,000,000	2,180	(2,080)[2]
Percent Hazardous Component Reduction	99.5%	99.9%	100%	95 %	100%	100%	100%	100%

Notes: [1] Excluding Treatment Process costs.
[2] Numbers in parenthesis indicate a debit.
[3] Waste streams 3,10,12 and 17 were dropped from consideration: See Section 5.1 for rationale.

TABLE 8 (continued)

BENEFIT ANALYSIS[1]

Columns	9	10	11	12	13	14	15	16
Waste Stream	9	11	13	14	15	16A	16B	18
Treatment System	09100	11100	13100	14100	15100	16_A100	16_B100	18100
Industry Category	HF Manufacture	Aluminum Fluoride Manufacture	Sodium Silico-fluoride Manufacture	Chromate Manufacture	Nickel Sulfate Manufacture	Phosphorus Manufacture		Phosphorus Chloride Manufacturing
Treatment Process	Evaporation & Asphalting	Evaporation & Asphalting	Evaporation & Asphalting	Calcination	HGMS	Calcination	Separation & Distillation	Distillation
Material Recovered	—	—	—	—	Nickel hydroxide	—	Phosphorus	Impure $AsCl_3$
Amount Recovered kkg/D	—	—	—	—	0.002 as 3% $Ni(OH)_2$	—	1.1	0.011
Resource Recovery Value $/Yr	—	—	—	—	590	—	321,000	Negligible
Resource Recovery Value $/kkg produce	—	—	—	—	0.01	—	6.50	Negligible
Savings in Waste Volume Reduction $/Yr. @ $6/kkg.	(184,100)[2]	(18,700)[2]	25,750	$109,500	(1,140)[2]	7,020	13,000	Negligible
Percent Hazardous Component Reduction	100%	100%	100%	100%	97 %	100%	92% (Single pass)	Essentially 100%

Air Pollution

Small quantities of air emissions emanate from the scrubber which is used to control the chlorine vapor from the vacuum filter and the hydrogen sulfide vapor from the treatment tank. Emissions from this stationary source have proven to be negligible and well within the limits of applicable regulations.

Water Pollution

The waterborne waste generated by this treatment process is the filtrate from the leaf filter operation which is neutralized and monitored for mercury content prior to discharge. The daily maximum mercury discharge from this operation is 0.045 kg (0.1 lb) [0.00018 kg/kkg of product] which is within the applicable NPDES permit range of 0.0000724 to 0.00286 kg/kkg [0.000145 to 0.00571 lb/ton] for mercury cell chlor-alkali plants

Solid Waste

There are 8.4 kkg/day of land destined waste removed from the settling tank and the vacuum filter. This waste contains less than 40 ppm of mercury on a dry weight basis which represents a 99.5 percent reduction of the hazardous component in the land destined waste.

Safety and Health Aspects

There are no major personnel safety hazards associated with this treatment process. Chlorine vapors from the vacuum filter and hydrogen sulfide vapors from the treatment tank are scrubbed and closely monitored. The recovered mercury product is in a dissolved form and presents no health hazard. Details on the occupational and health effects and information on applicable OSHA limitations for mercury and its salts, hydrogen sulfide and chlorine gas are given in Appendix 1.

5.1.1.1.4 Costs for Treatment System 1

a. Process Design and Cost Evaluation Bases

The fundamental design considerations used in estimating costs for this process are:

(1) Mercury-bearing sludges from a typical 250 kkg/day (275.5 tons/day) mercury cell chlor-alkali plant would be processed in this treatment plant at a rate of 0.81 kkg/hr (0.89 tons/hr), 24 hours per day, 365 days per year.

(2) A complete chemical reaction between the mercury present in the 18.5 kkg/day (20.4 tons/day) of brine purification muds, and 16 kkg/day (17.6 tons/day) of sodium hypochlorite reagent occurs forming a complex chloride ion in solution.

(3) Rotary vacuum filtration is used to effect removal of 8.4 kkg/day (9.3 tons/day) of inert solids from the mercury chloride solution. The solids contain a maximum mercury concentration of 40 ppm (dry basis) or 15 ppm (wet basis).

(4) Precipitation of mercuric sulfide from the mercury chloride solution is effected by the addition of sodium hydrosulfide. At this point, the mercury-bearing sludge from the plant's wastewater treatment operation (stream 2) is combined with the feed to the precipitation reactor. The process operates batchwise in succeeding operations.

(5) The insoluble mercuric sulfide in the sulfide-treated waste is recovered as filter cake [a total of 32.2 kg (70.8 lb) HgS per batch is processed]. The treated wastewater is within EPA discharge limits on mercury [<0.045 kg/day (<0.1 lb/day)] and is then routed to the plant outfall.

(6) Reaction of the insoluble mercuric sulfide with fresh sodium hypochlorite redissolves mercury which is recycled to the chlor-alkali process. The average Hg recycle rate is 0.04 kkg/day (0.44 tons/day).

b. Costing Methodology Used

For this process (system 01100), the total capital cost for the mercury recovery system was supplied by BASF Wyandotte. Cost for the typical plant was obtained by prorating the BASF cost on plant capacity using a 0.6 exponential scaling factor. Capital cost estimate was then changed from 1974 basis to 1976 by using the Chemical Engineering Plant Cost Indices.

The annual plant chemical, water, power and labor requirements were estimated from BASF-supplied information. However, EPA supplied standard cost factors, as discussed in Appendix II, were used to generate the operating costs. Costs for sampling, testing and miscellaneous other costs were prorated from BASF-supplied costs by using appropriate prorating and updating factors.

c. Cost Summary and Energy Requirement

The estimated total capital cost for system 01100 is $1,540,000. The system annual power requirement is 1,300,000 kwh. The annual process heat requirement is negligible. The unit operating costs (including credit for recovered mercury) are as follows:

$6.9 per kkg ($6.2/ton) of chlorine product

$361 per kkg ($328/ton) of waste (dry basis)

$89 per kkg ($81/ton) of waste (wet basis)

d. Detailed Process Equipment and Cost Information

Table 9 covers details on equipment sizes and operating conditions for this process. Capital cost and annual operating cost breakdowns for this plant are presented in Table 10.

5.1.1.2 Treatment Scheme 2 - Recovery of Mercury by Roasting of the Sludge

5.1.1.2.1 Process Description and Material Balance

The process consists of dewatering the sludge and roasting the mercury-bearing solids at 730° C to 760° C (1,350° F to 1,400° F) to vaporize and recover mercury from the sludge.

TABLE 9

SYSTEM 01100, EQUIPMENT NEEDS, SPECIFICATIONS AND OPERATING CONDITIONS

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
01101	1	18.9 l/min (5 gpm) centrifugal transfer pump - cast iron construction	Pumps slightly acidic slurry containing approximately 23% solids at 25°C (77°F) at head of approximately 30.5 m (100 ft).
01102	2	113,550 liter (30,000 gal) surge tank - FRP* construction	Tanks operate at 25°C (77°F) and 1 atm. Tanks can each hold approximately one week's supply of brind mud
01103	1	5,678 liter (1,500 gal) spent acid storage tank - FRP construction	Tank operates at 25°C (77°F) and 1 atm. Tank holds approximately 1 day's supply of 70% sulfuric acid
01104	1	3.78 l/min (1 gpm) acid metering pump - high silicon iron construction	Pumps 70% sulfuric acid at 25°C (77°F) at head of approximately 30.5 m (100 ft)
01105	2	10 HP SS turbine agitator	Operates at 25°C (77°F). Maintains uniform suspension of approximately 15% solids in tank
01106	1	37.85 l/min (10 gpm) centrifugal transfer pump - cast iron construction	Pumps acidic, 15% solids slurry at 25°C (77°F) at head of approximately 30.5 m (100 ft)
01107	1	15,140 liter (4,000 gal) sodium hypochlorite storage tank - FRP construction	Tank operates at 25°C (77°F) and 1 atm. Tank holds approximately 1 day's supply of sodium hypochlorite (7-8% available chlorine loading)
01108	1	11.36 l/min (3 gpm) metering pump - cast iron construction	Pumps sodium hypochlorite solution at 25°C (77°F) at head of approximately 30.5 m (100 ft)
01109	1	568 liter (150 gal) treatment tank - FRP construction	Tank operates at 25°C (77°F) and 1 atm. Provides 30 minutes residence time

* FRP = fiberglass reinforced plastic

TABLE 9 (continued)

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
01110	1	5 HP SS turbine agitator	Operates at 25°C (77°F). Maintains uniform suspension of approximately 10% solids in tank
01111	1	37.85 l/min (10 gpm) centrifugal transfer pump - cast iron construction	Pumps 10% brine muds slurry at 25°C (77°F) and head of approximately 30.5 m (100 ft)
01112	1	11.148 sq m (120 sq ft) rotary vacuum filter rubber-covered steel construction, polypropylene filter cloth	Operates at 25°C (77°F) and 38.1 cm (15 in) Hg vacuum. Dewaters solids to approximately 30% moisture content
01113	1	1,890 liter (500 gal) settling tank - FRP construction	Tank operates at 25°C (77°F) and 1 atm. Provides 1 hour residence time for any residual solids to settle to bottom of tank
01114	1	37.85 l/min (10 gpm) centrifugal transfer pump - cast iron construction	Pumps clear liquor from top of settling tank at 25°C (77°F) and head of approximately 30.5 m (100 ft)
01115	1	37,850 liter (10,000 gal) collection tank - FRP construction	Tank operates at 25°C (77°F) and 1 atm. Provides storage capacity for 1 batch of liquor to be treated in the next stage
01116	1	37.85 l/min (10 gpm) centrifugal transfer pump - cast iron construction	Pumps liquor from collection tank to sulfide treatment tank. Operates at 25°C (77°F) and head of approximately 30.5 m (100 ft)

TABLE 9 (continued)

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
01117	1	37,850 l/min (10,000 gal) treatment tank - steel w/rubber lining construction	Tank operates at 25°C (77°F) and 1 atm. Hydrogen sulfide vapor generated,is drawn through tank vent to scrubber 01124 using vacuum pump on rotary filter. Treatment cycle length is approximately 16 hours during which successive additions of sodium bisulfite, sulfuric acid and sodium hydrosulfide result in precipitation of mercuric sulfide
01118	1	1,140 l/min (300 gpm) centrifugal transfer pump - high silicon iron construction	Pumps HgS bearing liquor to horizontal pressure leaf filter. Pump operates at pressures up to 5 atm and 25°C (77°F)
01119	1	30.2 sq m (325 sq ft) horizontal pressure leaf filter - rubber-lined steel construction	Before filter is operated, filter leaves are precoated. Approximately 10 batches per week of slurry from treatment tank 01117 are pumped through, after which leaves are pulled and the cake dropped into redissolving tank 01120
01120	1	3,030 liters (800 gal) redissolving tank - polypropylene construction	Tank operates at 25°C (77°F) and 1 atm pressure
01121	1	1 HP turbine agitator	Operates at 25°C (77°F)
01122	1	189 l/min (50 gpm) centrifugal transfer pump-cast iron construction	Operates at 25°C (77°F) and head of approximately 30.5 m (100 ft)
01123	1	19 l/min (5 gpm) centrifugal transfer pump-cast iron construction	Operates at 25°C (77°F) and head of approximately 30.5 m (100 ft)

TABLE 9 (continued)

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
01124	1	1,500 liters (400 gal) packed scrubber - FRP construction	Operates at 25°C (77°F) with gas phase under negative pressure (gases are pulled through scrubber using vacuum pump 01130
01125	1	19 l/min (5 gpm) centrifugal transfer pump - cast iron construction	Operates at 25°C (77°F) and head of approximately 30.5 m (100 ft)
01126	1	Treated brine sludge storage bin, storage capacity is 7 cu m (250 cu ft) (1 day's production of brine purification solids) -mild steel construction	Treated sludge periodically removed and trucked to sanitary landfill. Treated sludge has less than 40 ppm Hg (wet basis)
01127	1	37,850 liters (10,000 gal) effluent holding tank - FRP construction	Operates at 25°C (77°F) and 1 atm pressure. Effluent batch is treated for Hg level and pH adjustment with NaOH to pH 7-9. Normal effluent discharge contains <0.02 kg/day (<0.044 lb/day) Hg
01128	1	190 l/min (50 gpm) centrifugal recirculating pump - cast iron construction	Operates at 25°C (77°F) and head of approximately 30.5 m (100 ft)
01129	1	190 l/min (50 gpm) centrifugal effluent discharge pump - cast iron construction	Operates at 25°C (77°F) and head of approximately 30.5 m (100 ft)
01130	1	2,300 l/min (800 SCFM) at 0°C (32°F), 1 atm mechanical vacuum pump with 58.5 cm (23 in) Hg vacuum capacity - steel construction	Operates at 25°C (77°F) and 38.1 cm (15 in) Hg vacuum
01131	1	5 HP SS turbine agitator	Operates at 25°C (77°F)

TABLE 10

CAPITAL COST AND ANNUAL OPERATING COSTS FOR TREATMENT SYSTEM 01100

CAPITAL INVESTMENT	$1,540,000
VARIABLE COSTS	
Treatment Chemicals *	61,000
Direct Operating Labor 2 men/shift @ $9/hr	158,000
Supervision and Administrative @ 50% of direct labor	79,000
Maintenance @ 4% of capital cost	62,000
Water **	700
Power, 1,300,000 kwh @ 3¢/kwh	39,000
Sampling and Testing	12,000
Waste Disposal, 8.4 kkg/day @ $6/kkg ($9.3 tons/day @ $5.44/ton) of wet waste	18,400
Miscellaneous Expenses **	16,000
Total Variable Cost	$446,100
FIXED COSTS	
Capital Recovery Rate (10 yrs @ 10%)	251,000
Taxes and Insurance @ 4% of capital cost	62,000
Total Fixed Cost	$313,000
TOTAL ANNUAL COST	759,100
Credit for recovery of mercury, 14,600 kg @ $9.08/kg (32,130 lb @ $4.13/lb)[17]	(132,800)
NET OPERATING COST	$626,300
Unit Costs	
$/kkg ($/ton) of chlorine	6.9 (6.2)
$/kkg ($/ton) of waste (dry basis)	361 (328)
$/kkg ($/ton) of waste (wet basis)	89 (81)

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*This item was given by BASF Wyandotte as a sum. However, these chemicals would include sodium hypochlorite, sodium sulfide (or hydrosulfide), sulfuric acid and caustic soda.

**Given by BASF Wyandotte as a sum.

The major pieces of equipment include a thickener, a rotary vacuum filter and a calciner/roaster. The brine purification mud (stream 1), containing about 23 percent by weight solids, is pumped from the main plant clarifier into the thickener which thickens the sludge to about 38 to 39 weight percent solids. The thickener underflow is dewatered in a rotary vacuum filter to a solids content of 60 percent. The filter cake is combined with wastewater treatment sludges (stream 2) and silica and roasted in the calciner. The purpose of the silica is to bind the salt in the sludge and prevent large clinker formation. All decanted and filtrate brine is recycled to the clarifier at the main plant.

If shower water is needed to clean the filter cloth or sluice out sludge buildups around the filter, brine from the clarifier overflow is used for this purpose and returned to the clarifier. During normal operating conditions, the clarifier overflow is sent to a settling pond. No fresh water is used for washdown.

The combustion gas stream from the furnace is passed through a cyclone, for particulate emission control, prior to mercury condensation and recovery. The off gases leaving the condenser are routed through a refrigerated heat exchanger and a demister for further mercury recovery The recovered mercury from the condenser and heat exchanger is collected in an accumulator and returned to the main plant for reuse.

Figure 21 shows a detailed flow sheet and material balance for a treatment plant to process waste sludges (streams 1 and 2) generated by a typical 250 kkg/day mercury cell chlor-alkali plant. Material balance and recovery values shown are prorated from a full-scale demonstration unit designed to handle 3.2 kkg/day dry solids in the roaster. The only adaptation made throughout the process is the assumption that silica addition would obviate the large clinker formation problems encountered during the plant operation.

5.1.1.2.2 Applications to Date

a. Full-Scale Treatment Installation

A full-scale demonstration plant to process sludges (waste streams 1 and 2) from a 181 kkg/day chlor-alkali mercury cell process has been designed, installed and operated by Georgia-Pacific at their plant in Bellingham, Washington, under the partial sponsorship of the Environmental Protection Agency.

The start-up was in early March, 1974 and the plant operators took over two months later. The plant operated for a few months without a major problem. From a design standpoint, the system worked better than expected. However, shortly after, several serious problems became apparent: (1) satisfactory continuous feeding of dewatered sludge was difficult to maintain; (2) severe corrosion in the roaster was apparent due to the acidic nature of the feed which was destroying the furnace rabble arms; and (3) high salt concentration of the feed was causing the roasted solid materials to form large clinkers which could not be properly discharged. Consequently, the screw feeder was replaced by a small belt

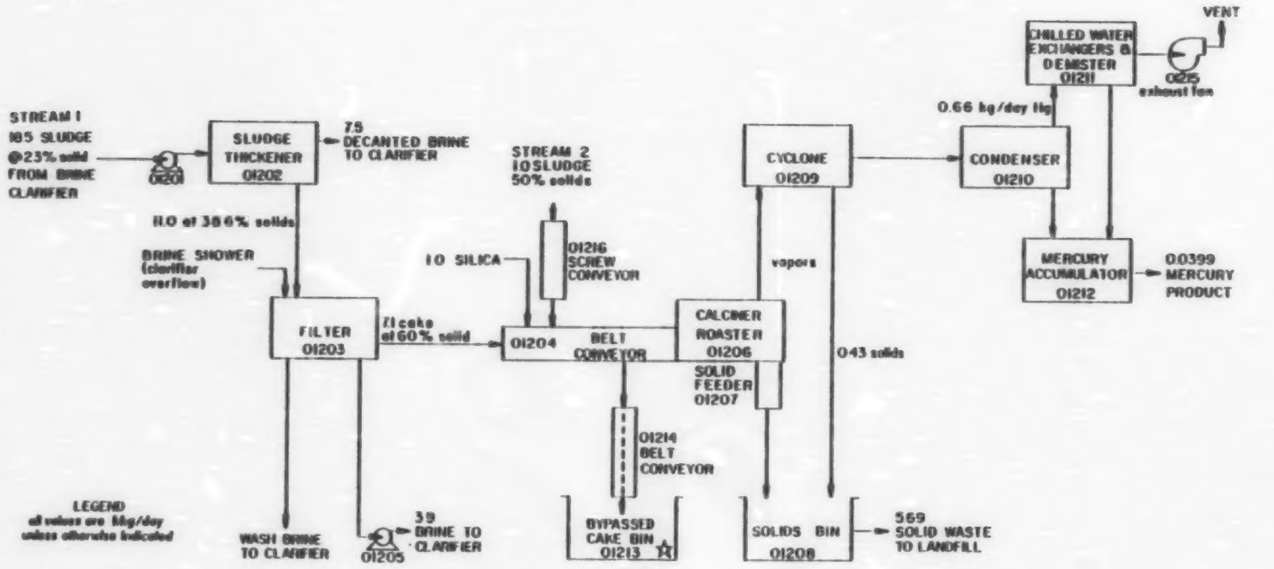
STREAM 1
185 SLUDGE
@23% solid
FROM BRINE
CLARIFIER
01201
SLUDGE THICKENER 01202
7.5
DECANTED BRINE
TO CLARIFIER
11.0 at 38.6% solids
BRINE SHOWER
(clarifier
overflow)
FILTER 01203
7.1 cake
at 60% solid
WASH BRINE
TO CLARIFIER
01205
3.9
BRINE TO
CLARIFIER
STREAM 2
1.0 SLUDGE
50% solids
01216
SCREW
CONVEYOR
1.0 SILICA
01204 BELT CONVEYOR
01214
BELT
CONVEYOR
BYPASSED
CAKE BIN
01213 ☆
CALCINER
ROASTER
01206
SOLID
FEEDER
01207
vapors
CYCLONE 01209
0.43 solids
SOLIDS BIN 01208
5.69
SOLID WASTE
TO LANDFILL
CONDENSER 01210
0.66 kg/day Hg
CHILLED WATER
EXCHANGERS &
DEMISTER
01211
0215
exhaust fan
VENT
MERCURY
ACCUMULATOR
01212
0.0399
MERCURY
PRODUCT
LEGEND
all values are Mkg/day
unless otherwise indicated

FIGURE 21 – MERCURY RECOVERY BY ROASTING OF THE SLUDGE (system 01200)

☆ THIS BIN WILL BE USED FOR INTERMITTENT STORAGE IF THE CALCINER IS SHUT DOWN FOR MAINTENANCE PURPOSES conveyor which proved to be a satisfactory means for feeding the sludge into the furnace. However, due to the inability of the plant to satisfactorily overcome the remaining two problems, the treatment plant has been shut down indefinitely. Mr. Don Elliot, plant manager is the key contact at this plant.

We believe that this process can be made operable by incorporating several modifications:

(1) The acid feed problem is believed to be unique to the Georgia-Pacific plant because the sludge is stored in an acid water pond. Normally, in other mercury cell plants, this sludge is stored on dry land and is essentially neutral in pH. This problem at Georgia-Pacific can be solved by neutralization of the sludge prior to roasting. However it is claimed that the roasting of acid sludges results in somewhat lower clinker mercury levels than for non-acidic sludges at the same temperature. The clinkering problem can probably be relieved by the addition of an appropriate quantity of silica to the roaster feed. The silica should bind the salt in the sludge and prevent large clinker formation.

(2) Should the incorporation of these modifications to the existing roaster operation prove to be unsuccessful, we believe the replacement of the existing multiple hearth furnace with a fluidized bed roaster to be an alternative solution to the clinker problem. A pilot plant demonstration run will be necessary to establish the validity of this contention.

b. Laboratory and Pilot Plant Operations[90]

Preliminary tests were conducted at Georgia-Pacific in a small lab muffle furnace. Crucibles of brine sludge were heated to several temperature levels for various lengths of time to determine the approximate temperature and time parameters.

Following the preliminary tests, a series of trials was conducted in a large kiln on samples ranging in size from 100 g to over 30 kg. The air rate through the kiln was carefully controlled to remove the vaporized mercury to prevent the vapor phase from becoming over-saturated with mercury. Residuals as low as 0.02 ppm mercury were achieved. Temperatures in the range of 800° C to 900° C (1,450° F-1,750° F) were required to achieve mercury residuals below 0.2 ppm.

Following the successful lab runs, kiln manufacturers were contacted to verify the laboratory data on a pilot scale. Tests were conducted at Bartlett-Snow, Cleveland, and BSP Division of Envirotech, Brisbane, California.

At Bartlett-Snow, a 15 cm (6 inch) diameter rotary calciner was operated at 800°C (1,475°F) with a residence time of 30 minutes. The minimum mercury level achieved in the tests was 25 ppm, which was significantly higher than that experienced during laboratory batch tests. The tests were shifted to a multiple hearth furnace to gain better control over residence time and eliminate short-circuiting.

A pilot run with a multiple hearth furnace was conducted at Envirotech. A 76 cm (30 in.) furnace was used at temperatures of 730°C to 760°C (1,350°F to 1,400°F). A somewhat higher solid feed was used in these tests and a residual mercury level of 0.14 ppm was achieved on the second run.

From these data, the maximum furnace hearth loading rate was found to be 39 kg/m^2 (8 lb/ft^2) per hour.

c. Pilot or Full-Scale Operations Treating Similar Wastes

Roasting and retorting methods are predominantly used for the recovery of mercury from cinnabar ore.

5.1.1.2.3 Benefits and Environmental Consequences

a. Benefit Analysis Information

The benefits resulting from roasting of mercury bearing sludges (streams 1 & 2) originating from mercury cell chlor-alkali plants are:

(1) elemental mercury recovery,

(2) solid waste reduction and

(3) solid waste detoxification.

A summary of the benefits achieved by this process is shown in column 2 of Table 8.

For the typical plant, this system recovers elemental mercury at a rate of 39.9 kg/day. Using a purchase price of $9.10 per kilogram of mercury, this treatment process would incur an annual resource recovery value of $132,500 or $1.45 per metric ton of chlorine produced.

The treatment plant will also achieve an annual cost savings of $13,820 resulting from the reduction of the volume of land destined wastes (excluding treatment process costs). The quantity of the solid waste generated by the treatment plant will be 5.69 kkg/day as compared to the original 12.0 kkg/day dewatered solid waste destined to landfills. Additionally, the solid waste will be essentially detoxified. The original waste contains 8,420 ppm mercury on a dry basis. The treated waste will contain less than 7 ppm mercury on a dry basis. This corresponds to a 99.9% reduction in mercury content of the land destined solid waste.

b. Environmental Impact

There are air emissions and land destined wastes generated by this treatment process. However, this process presents a minimal threat to the environment and personnel safety. The only serious issue is that the process is highly energy intensive.

Air Pollution

Limited quantities of air emissions will arise from the refrigerated heat exchangers which are used to condense the mercury vapors escaping from the water cooled condensers. The demonstrated mercury emission of 0.06 kg/day is estimated to be 2.6% of the present total allowable NESHAP limitations for mercury which permit no more than 2.3 kg/day of mercury vapor to be lost to the atmosphere from each mercury cell plant, regardless of size. Additionally, the vent gases will contain approximately 0.02 kkg/day particulates and 0.011 kkg/day sulfur dioxide which are well within the applicable limitations.

Water Pollution

There are no waterborne wastes from this treatment process. The brine generated from the sludge thickener (7.5 kkg/day) and the filter (3.9 kkg/day of brine) is recirculated to the clarifier at the main plant.

Solid Waste

There are 5.69 kkg/day land destined waste generated from the calcination/roasting operation. This waste contains less than 7 ppm of mercury which represents a 99.9 percent reduction of the hazardous component in the land destined waste.

Safety and Health Aspects

There are no major personnel safety hazards associating with this treatment process. The mercury vapor and the particulates from the refrigerated exchangers and demister are well below the applicable regulations and health standards. Details on the occupational and health effects and information on applicable OSHA limitations for mercury and its salts and sulfur dioxide are given in Appendix I.

5.1.1.2.4 Costs for Treatment System 2

a. Process Design and Cost Evaluation Bases

The fundamental design considerations used in estimating costs for this process are:

(1) Mercury-bearing sludges from a typical 250 kkg/day (275.5 tons/day) mercury cell chlor-alkali plant would be processed in this treatment plant at a rate of 0.81 kkg/hr, (0.89 tons/hr), 24 hours per day, 365 days per year.

(2) A thickener increases the solids content of the muds from 23% to 39%.

(3) Filtering this stream on a rotary vacuum filter produces 7.1 kkg (7.82 tons) per day of filter cake at 60% solids.

(4) Roasting the filter cake together with 1 kkg (1.1 tons) per day of mercury-bearing sludge from wastewater treatment and 1 kkg (1.1 tons) per day of silica removes essentially all of the mercury present in the sludges. The roasting process results in approximately 0.04 kkg/day (0.044 tons/day) of elemental mercury being liberated as vapor which is subsequently condensed and recycled to the mercury cell chlor-alkali plant. The 5.7 kkg/day (6.3 tons/day) of solids discharged from the roaster contain <10 ppm Hg.

b. Costing Methodology Used

For the mercury recovery process (system 01200), a breakdown of the total capital cost for the typical plant was obtained by prorating the Georgia-Pacific cost on plant capacity using a 0.6 exponential scaling factor. The capital cost estimate was then changed from 1974 to 1976 dollars by using the Chemical Engineering plant cost indices. The current cost of the multiple hearth roasting system was obtained from a vendor.[28] Also included is the total capital cost for this process using a fluidized bed roaster instead of a multiple-hearth furnace. Cost for fluidized bed roasting equipment versus multiple-hearth roasting were provided by Dorr-Oliver for a lime-burning operation.[78] The difference in costs for the lime-burning system was assumed applicable to the mercury sludge roasting operation.

The annual plant labor, power and fuel requirements were estimated from Georgia-Pacific supplied information. However, EPA-supplied standard cost factors, as discussed in Appendix II, were used to generate the operating costs.

c. Cost Summary

The estimated total capital investment for system 01200 is as follows:

Option 1 - Multiple-hearth sludge roasting system: $720,000

Option 2 - Fluidized bed sludge roasting system: $600,000

The estimated annual system power and heat requirements are 900,000 kwh and 4.94×10^9 kg cal (19.6×10^9 BTU), respectively.*

The unit operating costs (including credit for recovered mercury) are as follows:

Option 1 - System 01200A - Multiple-hearth sludge roasting system:

$2.9 per kkg ($2.6/ton) of chlorine product
$152 per kkg ($138/ton) of raw waste (dry basis)
$37 per kkg ($34/ton) of raw waste (wet basis)

Option 2 - System 01200B - Fluidized bed sludge roasting system:

$2.5 per kkg ($2.3/ton) of chlorine product
$134 per kkg ($121/ton) of raw waste (dry basis)
$32 per kkg ($29/ton) of raw waste (wet basis)

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*For the purpose of this study it has been assumed that the heat requirements are approximately equal for both types of roasters. However, fluidized bed systems use heat more efficiently than multiple-hearth systems.

d. Detailed Process Equipment and Cost Information

Table 11 lists details on equipment size and operating conditions for this process. Capital cost breakdown for this process is presented in Table 12. Tables 13 and 14 give detailed annual operating costs based on multiple-hearth roaster and fluid bed roaster operation, respectively.

5.1.2 Waste Stream 4, Asbestos Separator Wastes - Diaphragm Cell Process

A conceptual process design has been prepared for a treatment plant to destroy the asbestos fiber structure in this waste stream by fusion. Details on this process are given below.

5.1.2.1 Destruction of Asbestos by Fusion

5.1.2.1.1 Process Description and Material Balance

The process consists of mixing the waste sludge with anhydrous borax (fusion point lowering aid), drying and subsequent calcination of partially dried material to fuse the asbestos fibers into a solid mass. Because of the relatively small quantities of this material generated, the handling of the materials in and out of process units would be conducted manually.

The sludge is discharged into special ceramic trays positioned beneath the sludge discharge points. The trays are handled on roller conveyors and transported to a tunnel oven for drying. The oven is sized to handle 200 trays of sludge blend in 4 hours. Each tray holds 14.8 kg (32.5 lb) of sludge borax mixture. After the trays are removed from the tunnel dryer, they are then positioned on carriers and transported to an electric furnace for calcination at 1,000°C to 1,100°C (1,832°F to 2,012°F).

The furnace is designed to handle the entire anticipated daily load of 200 trays. The cold to cold calcination/fusion cycle is estimated to be 16 hours. The fused product can be safely disposed of in a sanitary landfill.

Figure 22 shows a detailed flow sheet and material balance for a treatment plant to process asbestos separator wastes generated by a typical 450 kkg/day diaphragm cell, chlor-alkali plant. Additionally, it has been assumed that the plant would incorporate into waste stream 4 a small quantity of smelter residue generated during the processing of waste stream 5. Both waste streams are generated at the same plant site. The smelter residue may contain asbestos fibers which should be detoxified.

5.1.2.1.2 Applications to Date

a. Full-Scale Treatment Installation

None known.

TABLE 11

SYSTEM 01200, EQUIPMENT NEEDS, SPECIFICATIONS AND OPERATING CONDITIONS

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
01201	1	37.85 l/min (10 gpm) centrifugal transfer pump - cast iron construction	Pumps 23% solids slurry to thickener; total head between 1-5 atm. Operates at 25°C (77°F).
01202	1	4.27 m (14 ft) diameter by 1.83 m (6 ft) high thickener-steel w/rubber lining construction	Operates at 25°C (77°F) and 1 atm. Thickens slurry to 39% solids
01203	1	1.8 m (6 ft) diameter by 2.4 m (8 ft) long rotary vacuum filter - steel with rubber lining construction	Feed rate of 10,000 l/day (2,640 gal/day) @ 39% solids; operates at 38 cm (15 in) Hg vacuum and 25°C (77°F); dewaters sludge to a filter cake containing 60% solids
01204	1	3.05 m (10 ft) long belt conveyor - rubber belting	Transfers 60% solids feed (filter cake plus stream 2 plus silica) to roasting furnace
01205	1	3.785 l/min (1 gpm) transfer pump - cast iron construction	Operates at 25°C (77°F) and total head between 1-5 atm.
01206	1	Calciner/roaster - refractory lined steel construction	Processes 9.1 kkg/day (10 TPD) of sludge with total water content of 4.3 kkg/day (4.7 TPD) and mercury content of 0.04 kkg/day (88 lb/day). Unit operates at 816-871°C (1,500-1,600°F) and 1 atm. pressure
01207	1	Solids feeder (screw-type) - mild steel construction	Discharges calcined solids from roaster at 816-871°C (1,500-1,600°F) and 1 atm. to solids collection bin

TABLE 11 (continued)

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
01208	1	7 cu m (250 cu ft) solids storage bin (holds one day's production of brine purification solids) - mild steel construction	Calcined solids are periodically removed and trucked to sanitary landfill. Residual Hg in calcined solids is <10 ppm
01209	1	Wet cyclone sized to remove 0.43 kg/day (0.39 TPD) solids from calciner/roaster outlet gas stream - mild steel construction	Cyclone operates at 85% efficiency; slurry of collected particulate drains into solids storage bin
01210	3	27.87 sq m (300 sq ft) water cooled cooler condensers-stainless steel construction	Condensers operate in series and remove approximately 83% of Hg vaporized which then drains to a mercury accumulator 01212.
01211	1	9.29 sq m (100 sq ft) chilled water-cooled condenser - stainless steel construction	System recovers 90% of residual Hg in the air stream from condensers 01210. Condensed Hg drains to accumulator 01212
01212	1	19 liters (5 gal) mercury accumulator - rubber-lined steel construction	Operates at 25°C (77°F) and 1 atm. Hg is periodically recycled to process
01213	1	7 cu m (250 cu ft) filter cake hold bin - holds 1 day's production; rubber-lined steel construction	Operates at 25°C (77°F) and 1 atm.
01214	1	6.1 m (20 ft) long belt conveyor - rubber belting	Transfers 60% solids mixture from filter cake hold bin to calciner/roaster
01215	1	1.420 l/min (500 SCFM) at 0°C (32°F), 1 atm induced draft fan	Exhausts the roaster unit gas stream through cyclone and condenser train. Gas discharge has 0.06 kg/day (0.132 lb/day) Hg, 11 kg/day (24.2 lb/day) SO_2 and 0.02 kkg/day (0.022 tons/day) of particulate

TABLE 11 (continued)

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
01216	1	45.4 kg/hr (100 lb/hr) screw feeder - stainless steel construction	Transfers 50% solids, mercury-bearing sludge from sludge sump to calciner/roaster

TABLE 12

TREATMENT SYSTEM 01200 - TOTAL INSTALLED CAPITAL COST

Equipment No. & Description		Installed Cost
01201	sludge transfer pump	$ 15,600
01202	sludge thickener and associated piping	71,800
01203	rotary vacuum filter	38,800
01204	belt conveyor	1,000
01205	filtrate transfer pump	1,000
01206	roasting furnace (multiple-hearth type), or	290,000
	roasting furnace (fluidized bed type)	175,000
01207	roasted solids screw feeder	8,100
01208	roasted solids holding bin	2,500
01209	wet cyclone	5,000
01210	cooler-condensers and associated piping	38,400
01211	refrigerated condenser and demister	15,000
01212	mercury accumulator	250
01213	filter cake hold bin	5,000
01214	belt conveyor	2,000
01215	induced draft fan and associated ducting	10,000
01216	wastewater sludge screw feeder	2,000
Miscellaneous Items		
structure, ladders and platform		61,000
site preparation and foundation		16,300
natural gas and water service		34,000
instrumentation and controls (other than roaster)		11,900
instrumentation and controls (multiple-hearth roaster)		24,000
instrumentation and controls (fluidized bed roaster)		14,000
painting and electrical		38,000
Sub-total (with multiple-hearth type)		$691,650
Sub-total (with fluidized bed type furnace)		$566,650
engineering, 2,200 manhours @ $15/manhour		33,000
Total investment, multiple-hearth type roaster		$724,650
Total investment, fluidized bed type roaster		$599,650

TABLE 13

ANNUAL OPERATING COSTS FOR TREATMENT SYSTEM 01200 BASED ON MULTIPLE-HEARTH ROASTER OPERATION (SCHEME 01200A)

CAPITAL INVESTMENT	$724,650
VARIABLE COSTS	
Silica (sand) 4050 kkg (4450 tons) @$41/kkg ($37/ton)[17]	15,000
Direct operating labor, 1 man/shift @ $9/hr	79,000
Supervision and Administrative @ 50% of direct operating labor	39,500
Maintenance @ 4% of capital investment*	29,000
Power, 900,000 kwh @ 3¢/kwh	27,000
Sampling and Analysis**	6,000
Waste Disposal, 5.7 kkg/day @ $6/kkg (6.3 tons/day @ $5.44/ton)	12,460
Process Heat Requirement, 4.94×10^9 kg cal @ $7.94/MM kg cal ($19.6 \times 10^9$ BTU @ $2.00/MM BTU)	39,200
Total Variable Costs	$247,160
FIXED COSTS	
Taxes and Insurance @ 4% of capital cost	29,000
Capital Recovery Rate (10 yrs @ 10% interest equivalent to 0.1627/yr)	119,000
Total Fixed Costs	$148,000
TOTAL OPERATING COST	$395,160
Credit for recovery of mercury, 14,600 kg @ $9.08/kg (32,120 lb @ $4.13/lb)[17]	(132,800)
NET OPERATING COST	$262,360
Unit Costs	
$/kkg ($/ton) of chlorine produced	2.9 (2.6)
$/kkg ($/ton) of waste (dry basis)	152 (138)
$/kkg ($/ton) of waste (wet basis)	37 (34)

---

* Georgia-Pacific personnel believe that this item should be 15% on investment, making the maintenance cost almost 50% of net operating cost.

** Versar estimate (assumed to be 1/2 the cost of the BASF process due to a simpler operation)

TABLE 14

ANNUAL OPERATING COSTS FOR TREATMENT SYSTEM 01200 BASED ON FLUIDIZED BED ROASTER OPERATION (SCHEME 01200B)

CAPITAL INVESTMENT	\$599,650
VARIABLE COSTS	
Silica (sand) 4050 kkg (4450 tons) @ \$41/kkg (\$37/ton)	15,000
Direct operating labor, 1 man/shift @ \$9/hr	79,000
Supervision and Administrative @ 50% of direct operating labor	39,500
Maintenance @ 4% of capital investment	24,000
Power, 900,000 kwh @3¢/kwh	27,000
Sampling and Analysis*	6,000
Waste Disposal, 5.7 kkg/day @ \$6/kkg (6.3 tons/day @ \$5.44/ton)	12,460
Process Heat Requirement, 4.94 x 10^9 kg cal @ \$7.94/MM kg cal (19.6 x 10^9 BTU @ \$2.00/MM BTU)	39,200
Total Variable Costs	\$242,160
FIXED COSTS	
Taxes and Insurance @ 4% of capital investment	24,000
Capital Recovery Rate (10 yrs @ 10% equiv. to 0.1627/yr)	97,000
TOTAL FIXED COSTS	\$121,000
TOTAL OPERATING COST	\$363,160
Credit for Recovery of mercury, 14,600 kg @ \$9.08/kg (32,120 lb @ \$4.13/lb)	(132,800)
NET OPERATING COST	\$230,360
Unit Costs	
\$/kkg (\$/ton) of chlorine produced	2.5 (2.3)
\$/kkg (\$/ton) of raw waste (dry basis)	134 (121)
\$/kkg (\$/ton) of raw waste (wet basis)	32 (29)

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*See note under Table 13

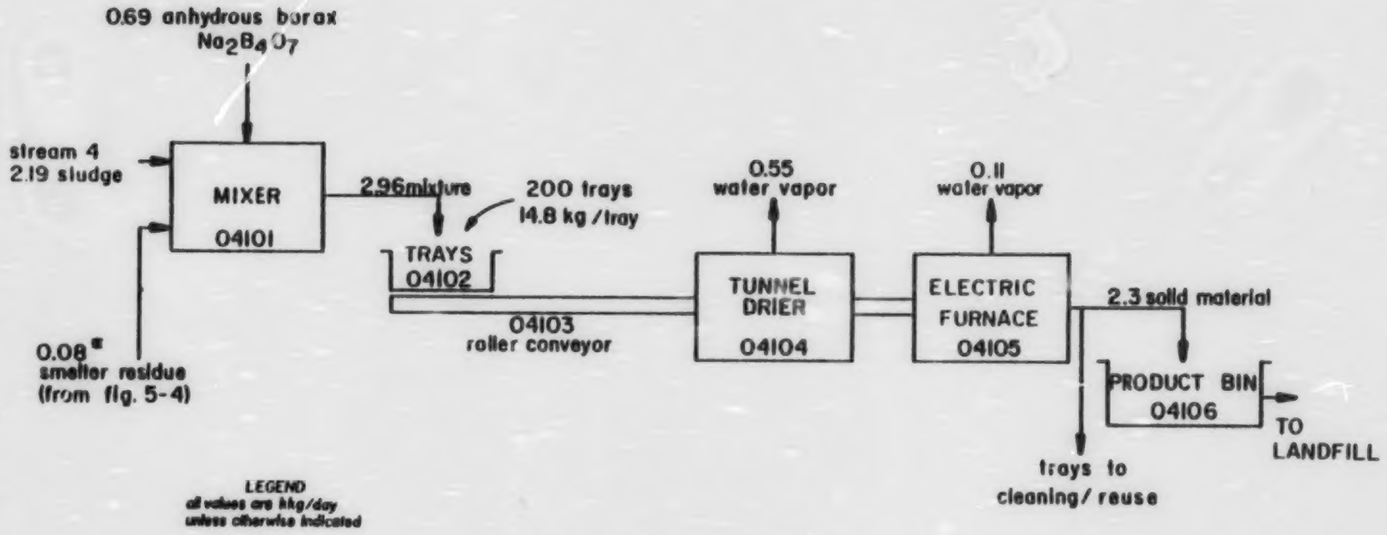
0.69 anhydrous borax
$Na_2B_4O_7$
stream 4
2.19 sludge
MIXER
04101
0.08*
smelter residue
(from fig. 5-4)
2.96 mixture
200 trays
14.8 kg/tray
TRAYS
04102
04103
roller conveyor
0.55
water vapor
TUNNEL
DRIER
04104
0.11
water vapor
ELECTRIC
FURNACE
04105
2.3 solid material
PRODUCT BIN
04106
TO
LANDFILL
trays to
cleaning/reuse
LEGEND
all values are kkg/day
unless otherwise indicated

FIGURE 22 – ASBESTOS DETOXIFICATION BY FUSION (system 04100)

* five day residue quantity prorated over a 7 day period

b. Laboratory and Pilot Plant Operations

Considerations in converting chrysolite asbestos waste to fosterite, a non-asbestos serpentine material, by heating to 600° - 900°C have been given by U.S. Bureau of Mines and ITT Research Institute who jointly presented this treatment technique at the Fifth Mineral waste utilization symposium held in Chicago, Illinois on April 13-14, 1976.

In November 1976, preliminary laboratory tests to establish the feasibility of the Versar suggested process were made by Arthur D. Little in their laboratory at Cambridge, Massachusetts. A 50/50 mixture by weight of borax and asbestos fibers was slurried in water, placed in a crucible and heated to 1,100°C. The mixture fused completely during this laboratory test.

Laboratory tests to optimize process conditions and pilot plant investigation to demonstrate the process would be required to validate this concept.

c. Pilot or Full-scale Operations Treating Similar Wastes

None known

5.1.2.1.3 Benefits and Environmental Consequences

a. Benefit Analysis Information

The benefit resulting from the fusion of asbestos bearing waste streams from diaphragm cell chlor-alkali plants is detoxification of the hazardous component in the waste stream. It is the fibrous structure of the asbestos that makes them hazardous and this process converts the fibrous structure to a fused, vitreous, non-hazardous form.

A summary of the benefits achieved by this system is given in column 3 of Table 8.

b. Environmental Impact

There would be solid waste generated by this system. However, this process presents a minimal threat to environment and personnel safety. The relatively large energy requirements associated with this process are a possible concern, but this too may be considered a minor issue considering the small volume of waste generated and treated by this process.

Air Pollution

The off-gas from the drier would contain only water vapor. The offgas from the electric furnace would contain small amounts of carbon dioxide (formed by the combusion of graphite in this sludge) and water vapor. Therefore, it is anticipated that there would be no emission problems associated with this process.

Water Pollution

None

Solid Waste

This process would generate approximately 2.3 kkg/day of waste which could be safely disposed of in a sanitary landfill.

Safety and Health Aspects

There are no serious personnel and safety hazards associated with this treatment process. The asbestos in this waste would be in slurry form during the mixing and tray loading operations, the trays from the drier would contain approximately 5-10% moisture and would have a clay like consistency and finally the fused product would contain no asbestos fibers. Details of the occupational and health effects of asbestos are given in Appendix 1.

5.1.2.1.4 Costs for Detoxification of Asbestos Separator Waste

a. Process Design and Cost Evaluation Bases

The fundamental design considerations used in estimating costs for this process are:

(1) Asbestos sludge would be fed to this plant at the rate of 2.27 kkg/day (2.50 tons/day), 365 days per year. This would include 2.19 kkg/day (2.41 tons/day) waste generated directly by asbestos separator teardown operations and 0.08 kkg/day (0.088 tons/day) smelter residue containing asbestos generated during the processing of lead bearing wastes from this plant.

(2) The 2.27 kkg/day (2.50 tons/day) of asbestos waste would be processed batchwise (one batch every 24 hours). Each batch would be blended with 0.69 kkg/day (0.76 tons/day) of borax*, placed in trays and dried to approximately 5% residual moisture. The trays are then placed in an electric calcination/fusion furnace at a temperature of 1,000-1,100°C (1,834-2,014°F) for a 16-hour programmed heating-cooling cycle (with 6 hours of treatment at the maximum temperature).

(3) There would be no asbestos particulate generated in either the mixing, drying or fusion operations.

b. Cost Methodology Used

With the exception of the electric furnace cost, which was supplied by a vendor, costs for this treatment process were developed using the standard methodology discussed in Appendix II.

c. Cost Summary and Energy Requirement

The estimated total capital cost for system 04100 is $211,000. The estimated annual power requirement is 580,000 kwh. The annual process heat (fuel) requirement is negligible.

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* Borax lowers the fusion point by forming a lower melting eutectic.

The unit operating costs are as follows:

$1.2 kkg ($1.1/ton) of chlorine produced

$360/kkg ($327/ton) of raw waste (dry basis)

$252/kkg ($229/ton) of raw waste (wet basis)

d. Detailed Process Equipment and Cost Information

Table 15 lists details on equipment sizes and operating conditions for this system. Breakdowns of total capital cost and annual operating costs are shown in Tables 16 and 17, respectively.

5.1.3 Waste Stream 5, Lead-containing Wastes - Diaphragm Cell Process

A conceptual process design has been prepared for a treatment plant to recover lead from this waste stream generated by the diaphragm cell process. Details on this process are given below.

5.1.3.1 Recovery of Lead by Smelting

5.1.3.1.1 Process Description and Material Balance

The process consists of adding a flocculant to the waste sludge to agglomerate small suspended particles, dewatering the wastes containing lead in a rotary vacuum filter to a solids content level of about 25 weight per cent, mixing the sludge with lime, silica and coke in a ribbon blender and then smelting the sludge in a reducing atmosphere at 1000° to 1040°C (1830° to 1,900°F) for lead recovery. Because small quantities of material would be handled at this treatment plant, the loading of the sludge on trays, the transferring of the trays into the smelter, the skimming of the dross (slag) from the molten lead and the pouring of the lead in ingots would be conducted manually.

The control technologies for particulate emission abatement from the smelter would be cyclone and baghouse collectors. Solids collected would be recycled back to the smelter.

The filtrate from the vacuum filter operation would be sent to the main plant water treatment system.

Figure 23 shows a detailed flow sheet and material balance for a treatment plant to process lead-containing wastes generated by a typical 450 kkg/day diaphragm cell chlor-alkali plant.

5.1.3.1.2 Applications to Date

a. Full-Scale Treatment Installation

None Known.

TABLE 15

SYSTEM 04100, EQUIPMENT NEEDS, SPECIFICATIONS AND OPERATING CONDITIONS

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
04101	1	1.4 cu m (50 cu ft) ribbon blender - mild steel construction	Operates at 25°C (77°F). Would blend total batch including 2.27 kkg (2.5 tons) of asbestos waste and 0.69 kkg (0.76 tons) of borax, in one hour
04102	200	0.07 cu m (0.25 cu ft) trays ("saggers") - holds one day's batch of blend produced in ribbon blender 04101 - perforated bottom, ceramic construction	Material would be hand-loaded into trays (~15 kg/tray (33 lb/tray) and placed on roller conveyor 04103
04103	1	9.14 m (30 ft) roller conveyor - mild steel construction	Would feed trays of asbestos sludge-fusion aid mix through tunnel drier 04104 at rate of 50 trays per hour
04104	1	7.62 m (25 ft) tunnel drier, heated by radiant heaters mounted above and below trays of material; 10 CFM (0.28 cu m/min) blower removes water vapor - mild steel construction	Operates at maximum temperature of 150°C (302°F) and 1 atm. Drier would remove 0.16 kkg/hr (0.18 tons/hr) of moisture from feed material. The feed would be dried to ~5% residual moisture over a four-hour period
04105	1	216 kw electric furnace with heating space of approximately 2.1 cu m (75 cu ft) and silicon carbide rod type heating elements - ceramic lined, mild steel construction	Trays of dried asbestos-bearing sludge would be hand-loaded into furnace. Furnace would operate at maximum temperature of 1,100°C (2,014°F) and 1 atm. Continuous air bleed through furnace would purge 0.11 kkg (0.12 ton) of water vapor per batch and any carbon dioxide formed by reaction of waste graphite present in the material being fused. Furnace cycle would include 8 hours of loading, 4 hours of heat up, 6 hours of fusion temperature and 6 hours of cooling time prior to unloading

TABLE 15 (continued)

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
04106	1	1.4 cu m (50 cu ft) hold bin (holds 1 batch of fused blocks formed in electric furnace) - mild steel construction	Fused blocks would be hand-unloaded from trays, and placed in hold bin until they could be loaded into trucks and hauled to a sanitary landfill

TABLE 16

TREATMENT SYSTEM 04100 - TOTAL INSTALLED CAPITAL COST

Equipment No. & Description		Installed Cost*
04101	ribbon blender	$ 5,000
04102	ceramic trays (200)	5,000
04103	roller conveyor	1,000
04104	tunnel drier	15,000
04105	electric furnace	100,000**
04106	hold bin	2,000
	Sub-total	$128,000
Building, 92.9 sq m @ $387/sq m (1,000 sq ft @ $36/sq ft)		36,000
	Sub-total	$164,000
Engineering @ 7%		11,500
	Sub-total	$175,500
Contingency @ 20%		35,100
	Total Installed Capital Cost	$210,600

---

* There is no significant piping and valve installation required for this process. Furthermore, cost for instrumentation is included in individual unit cost.

** Price supplied by Birkley Furnaces, Inc., Philadelphia, Pennsylvania

TABLE 17

ANNUAL OPERATING COSTS FOR TREATMENT SYSTEM 04100

CAPITAL INVESTMENT	$210,600
VARIABLE COSTS	
Treatment chemicals, borax, 262 kkg @ $192.5/kkg (289 tons @ $174.6/ton)[17]	50,400
Direct operating labor, 2 man/shift @ $9/hr	52,600
Supervision and Administrative, @ 50% of direct operating labor	26,300
Maintenance @ 4% of capital investment	8,400
Power, 580,000 kwh @ 3¢/kwh	17,400
Sampling and Analysis	5,000
Total Variable Costs	$160,100
FIXED COSTS	
Capital Recovery Rate (10 yrs @ 10% equiv. to 0.1627/yr)	34,200
Taxes and Insurance @ 4% of capital cost	8,400
Total Fixed Costs	$42,600
TOTAL OPERATING COST	$202,700
Unit Costs	
$/kkg ($/ton) of chlorine produced	1.2 (1.1)
$/kkg ($/ton) of raw waste (dry basis)	360 (327)
$/kkg ($/ton) of raw waste (wet basis)	252 (229)

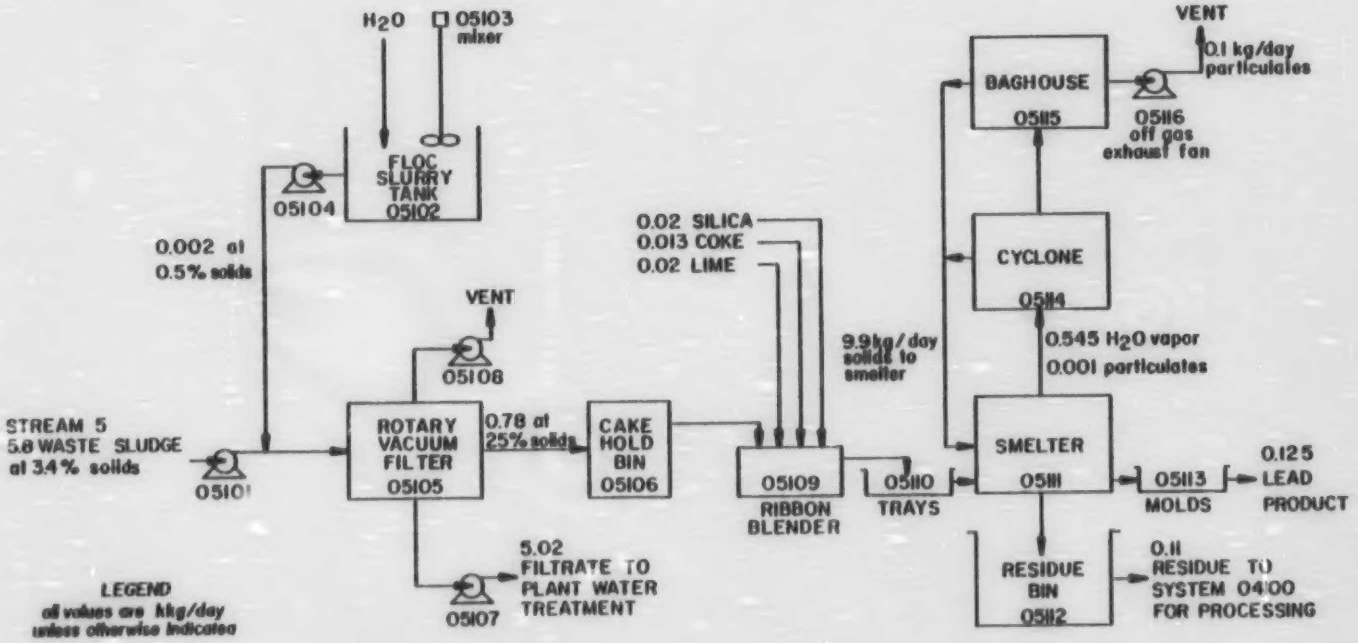
H2O
05103 mixer
FLOC SLURRY TANK 05102
05104
0.002 at 0.5% solids
STREAM 5 5.8 WASTE SLUDGE at 3.4% solids
05101
VENT
05108
ROTARY VACUUM FILTER 05105
0.78 at 25% solids
CAKE HOLD BIN 05106
05107
5.02 FILTRATE TO PLANT WATER TREATMENT
0.02 SILICA
0.013 COKE
0.02 LIME
05109 RIBBON BLENDER
9.9 kg/day solids to smelter
05110 TRAYS
SMELTER 05111
0.545 H2O vapor
0.001 particulates
CYCLONE 05114
BAGHOUSE 05115
05116 off gas exhaust fan
VENT
0.1 kg/day particulates
05113 MOLDS
0.125 LEAD PRODUCT
RESIDUE BIN 05112
0.11 RESIDUE TO SYSTEM 04100 FOR PROCESSING
LEGEND
all values are kkg/day unless otherwise indicated

FIGURE 23 — RECOVERY OF LEAD BY SMELTING OF DEWATERED SLUDGE (system 05100)

b. Laboratory and Pilot Plant Operations

There are no known pilot plant or laboratory operations utilizing this technology. However, all fundamental operations employed in this conceptual design are established unit processes. The process is believed to be technically feasible. However, laboratory tests to optimize processing conditions and a pilot plant to demonstrate the process would be required to validate this concept.

c. Pilot or Full Scale Operations Treating Similar Wastes

Smelting is used in secondary lead recovery operations. One facility in Reading, Pennsylvania processes scrap batteries for lead recovery. This plant uses a breaking operation to tear the batteries apart, drains the liquids and then processes the material through a gravity separator to recover lead and lead oxides. The lead-containing fraction is dried and dumped in a reverberatory furnace. The lead melts and separates from the dross which is skimmed off and the lead is poured to form ingots.

5.1.3.1.3 Benefits and Environmental Consequences

a. Benefit Analysis Information

The benefits resulting from the smelting of lead-bearing waste (stream 5) from diaphragm cell chlor-alkali plants are:

(1) the recovery of a small quantity of elemental lead and
(2) volume reduction of land destined waste.

For a typical plant, this system recovers lead at a rate of 0.125 kkg/day. Using a purchase price of $33 per kilogram of lead, this treatment process will result in an annual resource recovery value of about $10,725 or $0.065 per metric ton of chlorine produced.

The annual cost savings resulting from the volume reduction of land destined waste is estimated to be $8,880 (excluding treatment process costs). The 0.11 kkg/day of dross generated from the smelting operation may contain asbestos and as such would be either disposed of in a chemical landfill or be treated along with the asbestos-bearing waste (stream 4) generated at the same plant site.

A summary of the benefits achieved by this process is shown in column 4 of Table 8.

b. Environmental Impact

There are air emissions, waterborne waste and land destined waste generated from this treatment process. However, this process presents a minimal threat to the environment and personnel safety. The relatively large energy requirements associated with this process are a possible concern, but this too may be a minor issue considering the small quantity of waste that is to be treated.

Air Pollution

Limited quantities of air emissions would be released from the cyclone/baghouse system employed to control the particulates emission from the smelter. The particulate emissions from this system are estimated to be 0.1 kg/day which is well within the limits of applicable regulations.

Water Pollution

The waterborne waste generated from this treatment process would be the filtrate from the rotary vacuum filter containing dissolved solids. This filtrate would be sent to the plants' central wastewater treatment system at a rate of 4,990 liter/day (1,320 gal/day). It is anticipated that the lead content of this stream would be less than 0.2 ppm which is below the water quality limitation of 1.7 ppm for lead carbonate.

Solid Waste

There would be approximately 0.11 kkg/day of dross generated from the smelting operation. This waste would contain about 60 percent of asbestos and less than 3 percent of lead. Provisions have been made in this study to detoxify this waste stream along with the asbestos separator waste (stream 4) generated at diaphragm cell plant sites.

Safety and Health Aspects

There are no serious personnel safety hazards associated with this treatment process. The air emission would be well controlled by the cyclone/baghouse system. The solid residue from the smelter would be detoxified by fusion, and the waterborne waste, which contains low levels of lead, would be handled in the plant's wastewater treatment system.

The recovered lead would be in the elemental form and presents no safety hazards.

According to NARI ECO-technic news of 8 December 1976, the proposed OSHA regulations of 100 micrograms of lead per cubic meter of air, which was pending on the completion of an inflationary impact study, is now in the reviewing stage. Details on the occupational and health effects of lead and its salts are given in Appendix 1.

5.1.3.1.4 Costs for Recovery of Lead by Smelting

a. Process Design and Cost Evaluation Bases

The fundamental design considerations used in estimating costs for this process are:

(1) Lead-bearing sludges from a typical 450 kkg/day (495 tons/day) diaphragm cell chlor-alkali plant, would be processed in this treatment plant at the rate of 0.73 kkg/hr (0.8 tons/hr), 8 hours per day, 260 days per year. The lead is present as free lead metal as well as basic and acid forms of lead carbonate.

(2) The 5.8 kkg/day (6.4 tons/day) of sludge, containing approximately 3% solids, would be dewatered by vacuum filtration to produce 0.78 kkg/day (0.86 tons/day) of a filter cake containing 25% solids.

(3) The dewatered sludge would be combined with coke, lime and silica in the proportions 1.2% coke, 2.4% silica, 2.4% lime and 94% sludge. This mix would be then hand-loaded into a gas-fired reverberatory furnace in a batch operation. With appropriate temperature programming, the material would be first dehydrated, the lead carbonates would be next calcined to lead oxide, followed with the reduction of lead oxide to lead metal. The final reduction would be accomplished at approximately 1,100°C (1,900°F).

b. Costing Methodology Used

The standard methodology, discussed in Appendix II was used to develop costs for this treatment system.

c. Cost Summary and Energy Requirement

The estimated total capital cost for system 05100 is $314,000. The estimated annual system power and heat requirements are 50,000 kwh and 491×10^6 kg cal ($1,950 \times 10^6$ BTU), respectively. The unit operating cost (including credit for recovered lead), are as follows:

$0.81/kkg ($0.74/ton) of chlorine produced

$2,600/kkg ($2,360/ton) of waste (dry basis)

$91/kkg ($83/ton) of waste (wet basis)

d. Detailed Process Equipment and Cost Information

Table 18 lists details on equipment size and operating conditions for this process. Total capital cost breakdown is presented in Table 19 and overall capital cost and the annual operating cost breakdown for this plant are presented in Table 20.

5.1.4 Waste Stream 6, Metallic Sodium/Calcium Wastes - Down's Cell Process

A resource recovery process has been selected for treating calcium/sodium filter cake generated from the manufacture of metallic sodium by the Down's cell process. This process was used by Ethyl Corporation at their Baton Rouge plant prior to 1957. Details on this process are given below.

5.1.4.1 Recovery of Sodium Metal by Degrader Cell Process

5.1.4.1.1 Process Description and Material Balance

In this process, sludge is fed manually to electrolytic cells along with sodium chloride and reacted to form calcium chloride and metallic sodium according to the following reaction.

$$2\ NaCl + Ca \rightarrow CaCl_2 + 2\ Na$$

TABLE 18

SYSTEM 05100, EQUIPMENT NEEDS, SPECIFICATIONS AND OPERATING CONDITIONS

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
05101	1	15 l/min (4 gpm) centrifugal transfer pump - cast iron construction	Operates at 25°C (77°F) and head of approximately 30.5 m (100 ft)
05102	1	114 liters (30 gal) flocculant slurry feed tank - mild steel construction	Operates at 25°C (77°F) and 1 atm. Holds 3 months' supply of flocculant
05103	1	½ HP propeller agitator - mild steel construction	Operates at 25°C (77°F)
05104	1	250 ml/min (0.066 gpm) flocculant slurry injector-type metering pump - stainless steel construction	Operates at 25°C (77°F) and total pressure between 1-3 atm.
05105	1	15 l/min (4 gpm) rotary vacuum filter, 4.37 sq m (47 sq ft) filtration area - mild steel construction	Produces 780 kg (1,720 lb) per 8 hour day of filter cake @ 25% solids. Cake is discharged over 6-hour period. Operates at 25°C (77°F) and 38.1 cm (15 in) Hg vacuum
05106	1	2.8 cu m (100 cu ft) dewatered solids hold bin - mild steel construction	Operates at 25°C (77°F) and 1 atm. Holds 1 week's supply of dewatered sludge
05107	1	15 l/min (4 gpm) centrifugal transfer pump - cast iron construction	Pumps 5,000 l/day (1,320 gpd) of filtrate from the rotary vacuum filter (over 6-hour period) to plant wastewater treatment facility
05108	1	15 HP mechanical vacuum pump - mild steel construction	Operates at 25°C (77°F) and 38.1 cm (15 in) mercury working vacuum
05109	1	0.84 cu m (30 cu ft) ribbon blender - mild steel construction	Blend 818 kg/day (1,800 lb/day) of smelter feed composed of 1.2% coke, 2.4% silica, 2.4% lime and 94% sludge

TABLE 18 (continued)

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
05110	1	0.028 cu m (1 cu ft) smelter trays - ceramic lined, mild steel construction	Trays have about 50% freeboard to provide for volume expansion during smelting. Trays are loaded manually from ribbon blender and hold 20.4-22.7 kg (45-50 lb) of smelter feed each.
05111	1	Batch-operated fixed hearth reverberatory furnace - refractory lined, mild steel construction	Operates over temperature range of 25-1,040°C (77-1,900°F) with overall heat utilization efficiency of 40%. Smelter charge in trays is first dehydrated, lead carbonate is then calcined to lead oxide and lead oxide reduced to molten lead. Smelting operation produces one 125 kg (276 lb) batch per day of impure molten lead. Smelting heat cycle is 4 hours after which furnace is shut down and allowed to cool. Trays are manually unloaded and asbestos-rich slag is skimmed from surface of each tray and deposited in residue bin 05112.
05112	1	0.28 cu m (10 cu ft) slag bin (holds approximately 1 week's generation of slag from furnace) - mild steel construction	Operates at 25°C (77°F) and 1 atm. Asbestos-rich slag is periodically sent to process 04100 for treatment
05113	50	Lead ingot molds (holds one week's lead production) - cast iron construction	Molten lead from furnace is poured from trays into ten 12.5 kg (27.5 lb) each lead ingot molds daily and allowed to harden

TABLE 18′ (continued)

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
05114	1	8,500 l/min at 0°C, 1 atm (300 SCFM) cyclone - mild steel, refractory-lined construction	Operates over a temperature range of 25-260°C (77-500°F) with a pressure drop of 7.62-15.24 cm (3-6 in) of water and 75% operating efficiency
05115	1	8,500 l/min at 0°C, 1 atm (300 SCFM) fabric dust collector system	Operates over a temperature range of 120-260°C (250-500°F) and 99.5% operating efficiency
05116	1	8,500 l/min at 0°C, 1 atm (300 SCFM) induced draft off-gas exhaust fan - mild steel construction	Operates at a temperature of 150°C (302°F) and 1 atm

TABLE 19

TREATMENT SYSTEM 05100 - TOTAL INSTALLED CAPITAL COST

Equipment No. & Description	Installed Cost
05101 sludge transfer pump	$ 2,300
05102 slurry feed tank	200
05103 mixer	900
05104 injector metering pump	500
05105 rotary vacuum filter and associated piping, electrical and instrumentation	29,000
05106 dewatered solids hold bin	500
05107 filtrate transfer pump	3,400*
05108 mechanical vacuum pump	4,100*
05109 ribbon blender	6,000
05110 smelter trays (40)	4,000
05111 reverberatory furnace	150,000
05112 slag bin	500
05113 pig lead molds (50)	2,500
05114 cyclone	1,500
05115 fabric dust collection system	4,200
05116 induced draft fan	1,000
furnace instrumentation	30,000
Sub-total	$240,600
Piping and instrumentation @ 25% of equipment cost (other than furnace and rotary vacuum filter)	4,000
Sub-total	$244,600
Engineering @ 7%	17,100
Sub-total	$261,700
Contingency @ 20%	52,500
Total Installed Capital Cost	$314,200

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* Price supplied by Mr. R. Nielson, Ametek Corp., Rutherford, N.J.

TABLE 20

ANNUAL OPERATING COSTS FOR TREATMENT SYSTEM 05100

CAPITAL INVESTMENT	$314,200
VARIABLE COSTS	
Treatment Chemicals*	500
Direct operating labor, 2 men/shift @ $9/hr.	37,400
Supervision and Administrative @ 50% of direct labor	18,700
Maintenance @ 4% of capital cost	12,600
Water, 3.78 x 10^6 liters @7.9¢/1,000 l (1 x 10^6 gal @ 30¢/1000 gal)	300
Power, 50,000 kwh @ 3¢/kwh	1,500
Heat, 491 MM kg cal @ $7.94/MM kg cal (1950 MM BTU @ $2.00/MM BTU)	3,900
Sampling and Analysis	5,000
Total Variable Costs	79,900
FIXED COSTS	
Capital Recovery Rate (10 yrs. @ 10% equiv. to 0.1627/yr)	51,100
Taxes and Insurance @ 4% of capital cost	12,600
Total Fixed Costs	63,700
TOTAL OPERATING COST	143,600
Credit for recovery and sale of impure lead, 32,500 kg @ 33¢/kg** (71,500 lb @ 15¢/lb)	(10,725)
NET OPERATING COST	132,875
Unit Costs	
$/kkg ($/ton) of chlorine produced	0.81 (0.74)
$/kkg ($/ton) of waste (dry basis)	2,600 (2,360)
$/kkg ($/ton) of waste (wet basis)	91 (83)

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* lime, 5.7 kkg/yr (5.2 TPY) @ $27.50/kkg ($25/ton)	$130
coke, 2.9 kkg/yr (2.6 TPY) @ $55.00/kkg ($50/ton)	$130
silver, 5.7 kkg/yr (5.2 TPY) @ $48.00/kkg ($37/ton)	$188
	$448

** The selling price of pure lead is 44¢/kg (20¢/lb)[17]

Metallic sodium is removed from the cells through a riser pipe in the same manner as in Down's cells. The NaCl - $CaCl_2$ bath is removed from the cell periodically to maintain the proper NaCl - $CaCl_2$ balance in the cell. This material can be used in the Down's cells at the main plant.

To implement this treatment process in an existing facility, the waste filter cake would be removed from the existing sodium filters in the same manner as at present except that it would be molded into 5.65 kg bricks instead of in drums. The molds would be handled on roller conveyors until they are loaded into mold buckets. These would be transported to ovens for storage at 80° C (176° F) to prevent moisture pick up. The degrader cell would be a standard sodium cell modified to accept bricks of the waste filter cake and dry salt fed into the sodium collecting chamber. The bricks would be fed to the cell at a rate of 4 per hour per cell. In the cell the metallic sodium in the waste material would melt and would leave the cell along with sodium produced by electrolysis. The calcium would react with sodium chloride to produce sodium metal and calcium chloride. Sodium oxide and calcium oxide in the waste material would be decomposed electrolytically at the graphite cell anode to produce carbon monoxide or carbon dioxide. The gaseous products would be mixture of chlorine, hydrogen, oxygen as well as carbon monoxide and carbon dioxide. These gases would be scrubbed by dilute caustic in a high energy venturi scrubber which is expected to remove over 90 percent of the particulates and all of the chlorine in the gas stream.

The calcium-chloride sodium chloride mixture removed from the cell would be cast into buckets. The cast salt would be discharged to a grinder that feeds into a drier. The drier product would be drummed and used to replace the salt mixture as it becomes depleted in the Down's cells. The drier gases would be water scrubbed to remove particulates prior to venting.

After the sludge is removed from the molds, the molds would be steamed to removed any remaining metallic sodium, washed in hot water to remove caustic, dried and reused. The mold cleaning facilities are standard and available at all sodium manufacturing plants. Therefore, they are not included as a part of the treatment plant.

The dilute caustic scrubber liquors, the steam condensate and washwater from mold cleaning operations would be returned to the main plant and utilized as a source of weak alkali. The purge from the scrubber on the drier would be pumped to the plant outfall.

Figure 24 shows a detailed flow sheet and material balance for a treatment plant to process the waste calcium-sodium filter cake generated by a typical 140 kkg/day Down's cell plant. Material balance values are prorated from data supplied by Ethyl Corporation on actual plant operation. The treatment plant would produce 2.86 kkg/day (3.15 tons/day) of sodium, 43 percent of which would be sodium recovered from the waste stream and the rest from the salt added to the cell.

5.1.4.1.2 Applications to Date

a. Full-Scale Treatment Installation

The use of degrader cells to recover sodium from sodium-calcium filter cake was the process employed by Ethyl Corporation at Baton Rouge

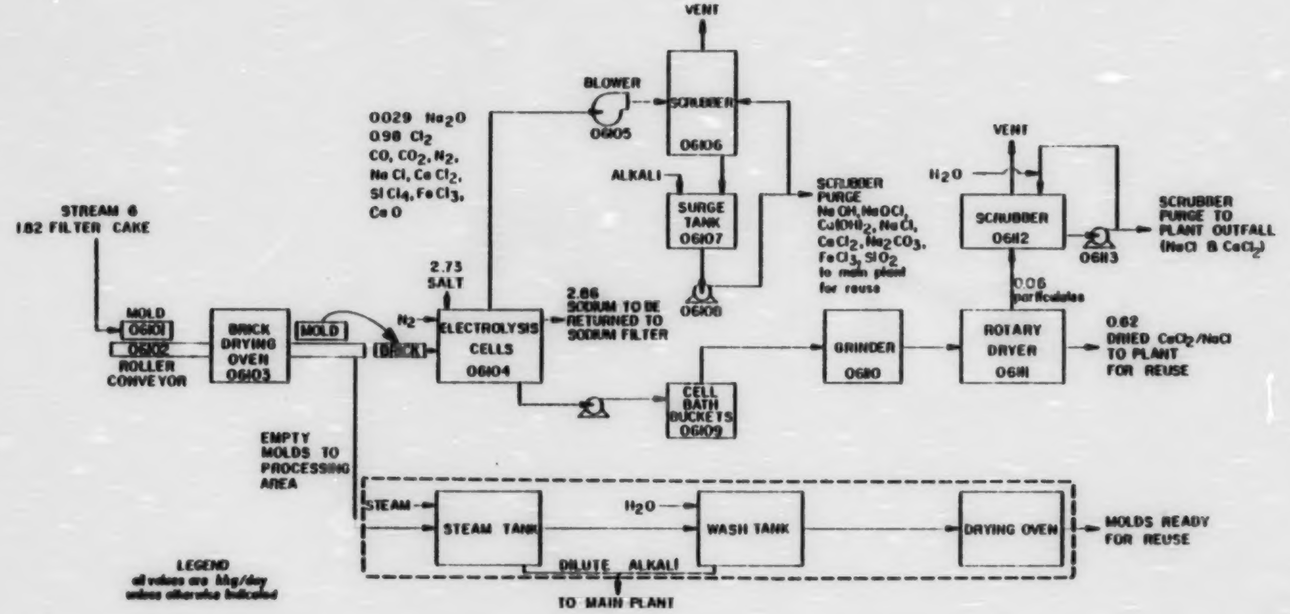
STREAM 6
1.82 FILTER CAKE
MOLD
06101
06102
ROLLER CONVEYOR
BRICK DRYING OVEN 06103
MOLD
BRICK
N_2
0029 Na_2O
0.98 Cl_2
CO, CO_2, N_2,
Na Cl, $CaCl_2$,
$SiCl_4$, $FeCl_3$,
Ca O
2.73 SALT
ELECTROLYSIS CELLS 06104
2.86 SODIUM TO BE RETURNED TO SODIUM FILTER
BLOWER
06105
VENT
SCRUBBER 06106
ALKALI
SURGE TANK 06107
06108
SCRUBBER PURGE
NaOH, NaOCl,
$Ca(OH)_2$, NaCl,
$CaCl_2$, Na_2CO_3,
$FeCl_3$, SiO_2
to main plant for reuse
CELL BATH BUCKETS 06109
GRINDER 06110
ROTARY DRYER 06111
0.06 particulates
0.62 DRIED $CaCl_2$/NaCl TO PLANT FOR REUSE
VENT
H_2O
SCRUBBER 06112
06113
SCRUBBER PURGE TO PLANT OUTFALL (NaCl & $CaCl_2$)
EMPTY MOLDS TO PROCESSING AREA
STEAM
STEAM TANK
H_2O
WASH TANK
DRYING OVEN
MOLDS READY FOR REUSE
DILUTE ALKALI
TO MAIN PLANT
LEGEND
all values are kkg/day unless otherwise indicated

FIGURE 24 — RECOVERY OF SODIUM METAL BY ELECTROLYSIS (system 06100)

until 1957 when a new disposal method (ocean dumping) was adopted in order to reduce:

(1) in-plant injuries,
(2) power consumption,
(3) operating costs and
(4) discharges to the atmosphere.

The Baton Rouge treatment plant had no emissions scrubbing facilities. The emissions from the cell were vented directly to the atmosphere. Furthermore, it was reported that, due to manual sludge molding and brick feeding operations, the safety record for the treatment plant was poor. The key contact at the Baton Rouge plant is Mr. J. D. Mueller.

b. Laboratory and Pilot Plant Operation

None known

c. Pilot or Full-Scale Operations Treating Similar Wastes

None known

5.1.4.1.3 Benefits and Environmental Consequences

a. Benefit Analysis Information

The benefits resulting from the electrolysis of sodium/calcium bearing sludge (stream 6) from the Down's cell process are:

(1) sodium metal recovery,
(2) calcium chloride/sodium chloride ($CaCl_2$ - NaCl cell bath) recovery and
(3) solid waste elimination.

This system would recover elemental sodium and cell bath ($CaCl_2$-NaCl mixture) at a rate of 2.86 kkg/day and 0.62 kkg/day, respectively. Using a price of $290/kkg for the recovered sodium and $116/kkg of cell bath salt (prices supplied by Ethyl Corporation), this process would result in a resource recovery value of $328,980 or $6.44 per metric ton of chlorine produced.

The resource recovery of the hazardous portion of this waste stream achieved by the utilization of this process will also result in an annual cost savings of $231,000 assuming this waste was previously ocean dumped at $100 per drum (excluding treatment process costs). The cost of $100 is based on an assumption that the wastes would be handled in 20 drum lots and the drums would be punctured by rifle fire, prior to dumping, while attended by the Coast Guard.[94]

A summary of the benefits achieved by this process is shown in column 5 of Table 8.

b. Environmental Impact

There are air emissions generated by this process. The gases and the particulates emitted from the cell would require, at a minimum, a high energy venturi scrubber to provide adequate environmental protection. Additionally, the safety considerations described below, and the large electrical energy requirements associated with this process are of concern.

Air Pollution

The gases emitted from the cell contain Cl_2, CO, CO_2, O_2 and particulate Na_2O, CaO, NaCl and $CaCl_2$. The gases would be scrubbed with an alkali solution in a high energy venturi scrubber with a particulate removal efficiency of over 90%. Another wet scrubber will be used to scrub the particulates emanating from the cell bath salt rotary drier. It is expected that air emissions from these two stationary sources will be negligible and well within applicable limitations.

Water Pollution

A small quantity of scrubber liquor is intermittently purged from the wet scrubber on the cell bath salt drier. This waterborne waste contains dissolved solids (NaCl and $CaCl_2$) and is pumped to the plant outfall.

Solid Waste

There is no solid waste generated by this process.

Safety and Health Aspects

Past experience by Ethyl Corporation at their plant in Baton Rouge indicated a poor safety record for this operation. The time-losing accident frequency rate during the final three years of degrader cell operation was reported to be 33% higher than for the remainder of the sodium plant because of the hazardous nature of the operation. Some of these accidents are given below:

"Thermal and caustic burns were received from the splashing or spattering of molten sludge as it dropped into the molds. Over-filling of the molds caused spillage of molten sludge and resulted in additional spattering.

The handling of the molds and the bricks resulted in occasional thermal or caustic burns.

Brushing against sludge bricks that were damp due to condensation of water vapor caused some of the concentrated caustic on the surface of the bricks to rub off onto skin or clothes. The result varied from skin irritation to caustic burns."

Most of the injuries reported were due to a number of manual handling operations practiced at that plant. It is anticipated that the mechanization of sludge handling and feeding would minimize the accidents and would make this treatment process acceptable and safe. The basic process concept used at Baton Rouge is reportedly still being employed by at least one commercial sodium producer. Details of this operation have not been divulged. However, this plant has indicated that the treatment plant area accident rate is not any greater than that of the main plant.

5.1.4.1.4 Costs for Recovery of Sodium Metal by Degrader Cell Process

a. Process Design and Cost Evaluation Bases

The fundamental design considerations used in estimating costs for this process are:

(1) Sodium-calcium filter cake waste from a typical 140 kkg/day (154 tons/day) Down's cell sodium plant is processed in the treatment plant at the rate of 0.076 kkg/hr (0.084 TPH), 24 hours per day, 7 days per week, 365 days per year.

(2) The feed rate to these cells is 21.8 kg (48 lb) of waste per hour.

(3) The electrolytic process requires the addition of 1.5 kkg (1.7 tons) of salt per kkg of waste processed. The overall sodium recovery (both from melting and electrolysis) is 1.57 kkg (1.73 tons) of sodium per kkg of waste processed.

(4) The by-product sodium chloride-calcium chloride melt is recovered at the rate of 0.62 kkg/day (0.68 tons/day).

(5) Raw waste from the degrader cell process consists of cell emissions including particulate (expressed as approximately 0.01 kg Na_2O per kg of recovered sodium) and chlorine from salt electrolysis (given as approximately 0.6 kg per kg of recovered sodium).

b. Costing Methodology Used

An economic analysis was made by Ethyl Corporation in 1976 for processing 907 kkg (1,000 tons) per year of sodium-calcium waste by the degrader-cell technique.[60] These costs were used as the basis for these estimates. Appropriate adjustments were made to reflect the plant size differences and to incorporate the standard operating cost factors supplied by EPA.

c. Cost Summary and Energy Requirement

The total capital cost for system 06100 is estimated to be $1,410,000. The annual system power requirement is estimated as 11,000,000 kwh. The annual heat requirement is estimated as 169.3×10^6 kg cal (672×10^6 BTU). The unit operating costs, including credit for recovered sodium and cell bath, are as follows:

$44/kkg ($40/ton) of sodium product
$3,170/kkg ($2,876/ton) of waste (no water present in this waste)

d. Detailed Process Equipment and Cost Information

Table 21 covers details on equipment sizes and operating conditions for the sodium recovery system. Total capital investment and the annual operating cost breakdowns for this plant are presented in Table 22.

TABLE 21

SYSTEM 06100, EQUIPMENT NEEDS, SPECIFICATIONS AND OPERATING CONDITIONS

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
06101	80	Sodium-calcium waste molds. Molds can hold one day's production of waste - mild steel construction	Molds constructed to withstand operating temperatures up to 200° C (392° F)
06102	2	6.1 m (20 ft) roller conveyor- mild steel construction	Oqerates at 25° C (77° F)
06103	1	2.8 cu m (100 cu ft) holding oven - capacity for one day's production of waste stored in molds - mild steel construction	Steam-heated hot air circulation. Oven kept at 75° C (167° F) and 1 atm. pressure
06104	10	Degrader cells - these are standard Down's cells specially converted to reclaim the sodium calcium waste	Operate at 500-600° C (933-1113° F) and 1 atm. Four cells are always undergoing rebuilding with four others on line. Average life of cells in degrader operation is 50 days. Cells are suitably enclosed and vented to a common vapor exhaust manifold.
06105	1	2,830 l/min (100 CFM) gas blower - cast iron construction	Operates at an average temperature of 300° C (573° F) and 1 atm. Exhausts gases from degrader cells and blows this stream through a venturi scrubber
06106	1	High energy jet venturi scrubber with 190 l/min (50 gpm) of recirculating 5% caustic as scrubbing media. Operates at 99% efficiency - cast iron construction	Operates at gas inlet temperature of 300° C (573° F) and gas outlet temperature of 150° C (302° F). Absorbs 1 kg/hr (2.2 lb/hr) of Na_2O particulate and 40 kg/hr (88 lb/hr) of chlorine.
06107	1	2,300 liters (600 gal) scrubber liquor surge tank - holds approximately 1 hour's supply of dilute caustic - mild steel construction	Operates at 25° C (77° F) and 1 atm.

TABLE 21 (continued)

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
06108	1	38 l/min (10 gpm) scrubber liquor pump - cast iron construction	Operates at 25° C (77° F) and total head of approximately 30.48 m (100 ft.)
06109	60	11 kg (25 lb) cell bath buckets - mild steel construction	-
06110	1	10 HP cell bath grinder - mild steel construction	Grinds 680 kg/day (1,500 lb/day) chunks of cell bath to 10-20 mesh powder
06111	1	680 kg/day (1,500 lb/day) gas-fired rotary drier - mild steel construction	Operates at 150° C (302° F) and 1 atm. - removes approximately 2% moisture from ground cell bath
06112	1	Wet scrubber - water scrubs 0.06 kkg/day (0.066 tons/day) of NaCl and $CaCl_2$ particulate from exit gases leaving cell bath drier - mild steel construction	Operates at temperatures between 50°-100° C (122°-210° F) and 1 atm.
06113	1	19 l/min (5 gpm) recirculating scrubber liquor pump - cast iron construction	Recirculates scrub liquor until saturated - pumps purge stream to plant outfall

TABLE 22

TREATMENT SYSTEM 06100 - TOTAL CAPITAL AND ANNUAL OPERATING COSTS

CAPITAL INVESTMENT*	
Waste molding facilities**	$332,000
Degrader cells	415,000
Gas scrubbing and cell bath recovery	662,000
Total Installed Cost	1,409,000
VARIABLE COSTS	
Sodium Chloride, 1,000 kkg @ $14.50/kkg (1,102 tons @ $13.15/ton)	14,500
Direct operating labor, 36 men/ 3 shifts @ $9/hr/man	945,000
Supervision and Administrative @ 50% of direct operating labor	472,000
Maintenance (other than cell maintenance) @ 4% of capital investment	37,000
Operating Supplies	127,000
Sampling and Analyses	22,000
Cell Diaphragm changes 273 changes/yr @ $500/change	136,000
Cell Rebuilding 13 cells @ $17,000/cell	221,000
Power Cost, 11.0 MM kwh @ 3¢ kwh	331,000
Process Heat, 169.3 MM kg cal @ $7.94/MM kg cal (672 MM BTU @ $2.00/MM BTU)	1,300
Total Variable Cost	2,306,800
FIXED COSTS	
Capital Recovery Rate (10 yrs @ 10% equiv. to 0.1627/yr)	229,000
Taxes and Insurance @ 4% of capital investment	56,000
Total Fixed Cost	285,000
TOTAL ANNUAL COST	2,591,800

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* Prorated for size of plant from information supplied by Ethyl Corporation. No building cost is provided in this estimate since the cells and related facilities are housed in the main plant. Piping and valve costs, as well as engineering costs, are assumed to have been included in the Ethyl Corp. information.

** Mold washing and drying equipment are part of main plant facilities. Costs given are for waste molding operation only.

TABLE 22 (continued)

Less Credits:	
Recovered Sodium	(303,000)
1,046,000 kg @ 29¢/kg	
(2,301,200 lb @ 13¢/lb)*	
Recovered cell bath (as calcium chloride)	(26,200)
226 kkg @ $116/kkg	
(249 tons @ $105/ton)*	
TOTAL CREDITS	(329,200)
NET OPERATING COST	2,262,600
Unit Costs	
$/kkg ($/ton) of sodium produced	44 (40)
$/kkg ($/ton) of waste	3,170 (2,876)

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* These values furnished by Ethyl Corp.

5.1.5 Waste Stream 7, Wastewater Treatment Sludges, Titanium Dioxide, Chloride Process

A conceptualized detoxification process has been selected for treating chromium hydroxide bearing sludges generated from the chloride process for the manufacture of titanium dioxide. The process involves dewatering of the sludge to the extent possible and subsequent calcination to convert the metal hydroxides to oxides. The resulting chromium trioxide (Cr_2O_3)-bearing material is insoluble in acid, alcohol and alkali. Therefore the calcined waste can be disposed off in sanitary landfills with no adverse environmental effects. Details on this process are given below.

5.1.5.1 Detoxification of Metal Hydroxides by Calcination

5.1.5.1.1 Process Description and Material Balance

The major equipment in this system consists of a thickener, a rotary vacuum filter, a drier and a rotary kiln. The waste treatment sludges containing about 5 weight percent solids would be pumped from the main plant into the sludge thickener. Flocculant would be added to the incoming sludge to agglomerate small suspended particles. The thickener would increase the sludge solids concentration from 5 to 9 percent. The underflow from the thickener would be further dewatered in a rotary vacuum filter to a solids content of 25 percent. The filter cake would be washed with fresh water to minimize the chloride carry over, and would then be conveyed to a rotary kiln, where the cake would be calcined at a temperature of 1000° C (1830° F). The detoxified product from the calciner would be collected in a bin for subsequent disposal in a sanitary landfill. Overflow from the thickener and the filtrate from the rotary vacuum filter would be sent to wastewater treatment. The gases from the calciner would be processed through a cyclone and subsequently scrubbed for particulate and hydrochloric acid mist control. The scrubber liquor could be recycled with an intermittent purge returned to the calciner.

Figure 25 shows a detailed flow sheet and material balance for a treatment plant to process waste sludges generated by a 100 kkg/day titanium dioxide plant using the chloride process and ilmenite ore as feed. The material balance for the dewatering circuit is prorated from an existing operation. Due to the nature of the metal hydroxides involved, the sludge is gelatinous and is not easily dewatered to levels greater than 25 percent solids.

5.1.5.1.2 Application to Date

a. Full-Scale Treatment Installation

There are no known full scale treatment plants using the selected process in its entirety for treating wastewater treatment sludges generated from the chloride process. However, the dewatering circuit of this system is currently being used by at least one manufacturer in this category. The New Jersey Zinc Company dewaters the metal hydroxide sludges generated by a 75 kkg/day titanium dioxide plant in Ashtabula, Ohio in a thickener/vacuum filter system. The filter cake is presently sent to a land disposal site.

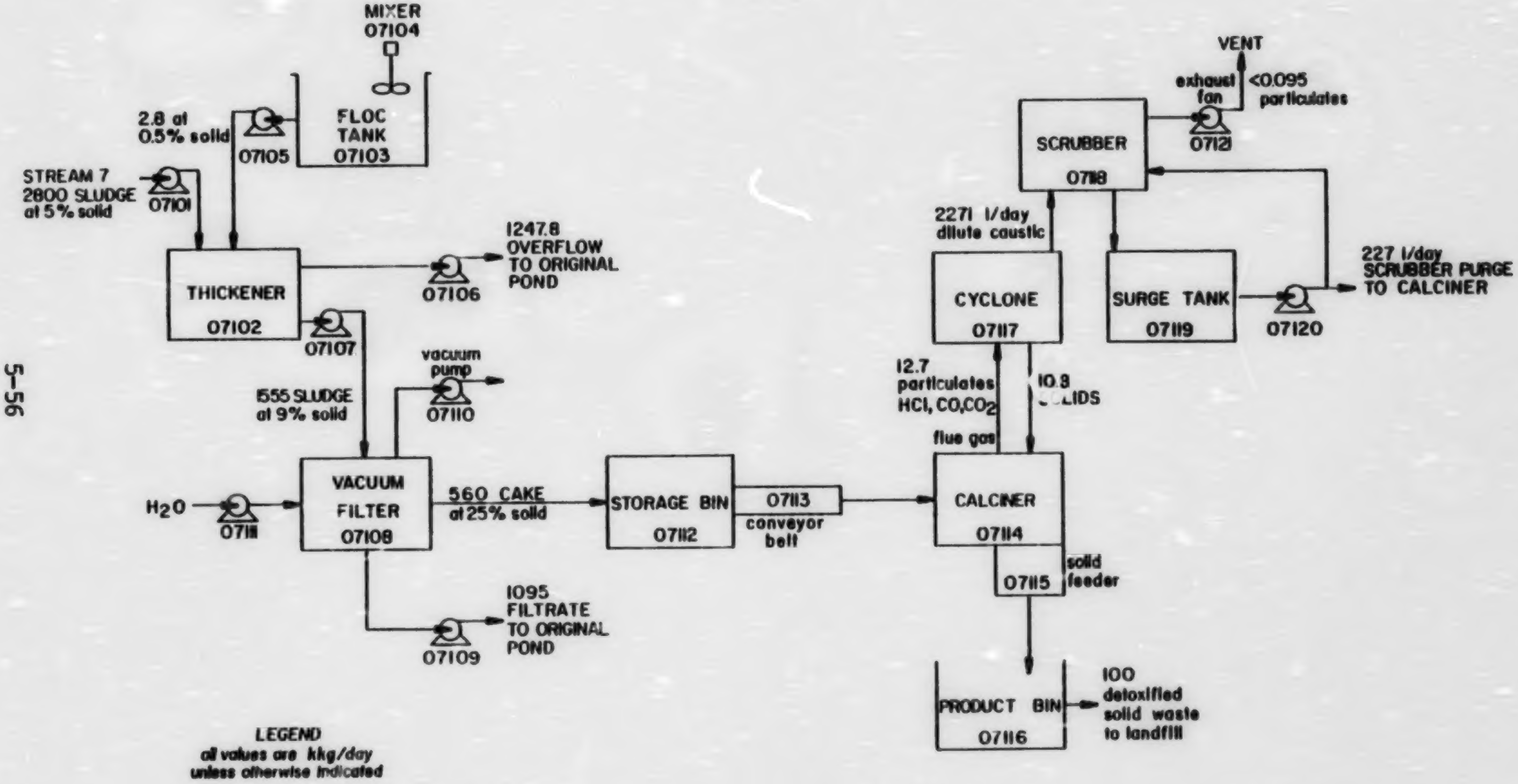
MIXER 07104
FLOC TANK 07103
2.8 at 0.5% solid
07105
STREAM 7 2800 SLUDGE at 5% solid
07101
THICKENER 07102
1247.8 OVERFLOW TO ORIGINAL POND
07106
07107
1555 SLUDGE at 9% solid
vacuum pump
07110
H_2O
07111
VACUUM FILTER 07108
560 CAKE at 25% solid
1095 FILTRATE TO ORIGINAL POND
07109
STORAGE BIN 07112
07113
conveyor belt
CALCINER 07114
07115
solid feeder
PRODUCT BIN 07116
100 detoxified solid waste to landfill
flue gas
12.7 particulates HCl, CO, CO_2
10.8 SOLIDS
CYCLONE 07117
2271 l/day dilute caustic
SCRUBBER 07118
exhaust fan
07121
VENT
<0.095 particulates
SURGE TANK 07119
07120
227 l/day SCRUBBER PURGE TO CALCINER
LEGEND
all values are kkg/day unless otherwise indicated

FIGURE 25 – DETOXIFICATION OF METAL HYDROXIDES BY CALCINATION (system 07100)

The overflow from the thickener is discharged after passing through a polishing pond. The filtrate is recycled to the main plant clarifier. The key contact at New Jersey Zinc is Mr. Jerome F. Smith, Director of Environmental Technology.

b. Laboratory and Pilot Plant Operation

Extensive laboratory and pilot plant dewatering tests have been conducted by New Jersey Zinc Company, to increase the sludge solids concentration to a level greater than 25 weight percent thereby reducing the quantity of waste to be landfilled, with no appreciable success.

Calcination is an established unit operation. However, there are no known plants in this industry using this unit process for this purpose. Therefore, laboratory and pilot scale runs would be required to optimize processing conditions and to validate this concept.

c. Pilot or Full-Scale Operations Treating Similar Wastes

Calcination is an established process for dehydrating aluminum hydroxide in the alumina manufacturing industry. This operation is normally conducted at temperatures of 1000° C - 1093° C (1830° - 2000°F).

5.1.5.1.3 Benefits and Environmental Consequences

a. Benefit Analysis Information

The benefits resulting from calcination of chromium hydroxide bearing wastes which result from titanium dioxide manufacture (chloride process) are:

(1) solid waste detoxification and
(2) solid waste reduction.

The major benefit achieved by this system is the complete detoxification of chromium hydroxide by conversion to the less soluble chromium oxide which is insoluble in acid, alkali and water. Additionally, this system would achieve an annual cost savings of $1,000,000 resulting from the reduction of the volume of wastes to be disposed of (excluding treatment process cost).

A summary of the benefits achieved by this process is shown in column 6 of Table 8.

b. Environmental Impact

There are air emissions and solid wastes generated by this treatment process. However, this process presents a minimal threat to the environment and personnel safety. The only serious issue associated with this process is that it is highly energy intensive.

Air Pollution

Small quantities of air emissions will be released from the scrubber on the rotary kiln used to abate the hydrogen chloride and particulates in the flue gas. The vent gases from the scrubber would contain approximately 0.095 kkg/day of particulates which is well within the present applicable limitations.

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Water Pollution

Two waterborne waste streams are generated. These are: (1) the overflow from the thickener (1,240,000 liters/day) and (2) the filtrate from the vacuum filter (1,000,000 liters/day). Both streams would be sent to the plant's waste water treatment system. A known plant, which employs this dewatering system, sends the filtrate to the main plant clarifier. The overflow from the clarifier is combined with the thickener overflow and settled in a polishing pond prior to discharge. The scrubber purge would be fed to the calciner.

Solid Waste

There would be approximately 100 kkg/day of detoxified waste generated by this system which could be disposed of in a sanitary landfill. This system reduces the waste quantity by 82 percent.

The 10.8 kkg/day solid particulate matters trapped by the cyclone on the off gases of the kiln would be returned to the rotary kiln.

Safety and Health Aspects

There are no personnel and safety hazards associated with this treatment process. The hydrogen chloride mist in the kiln offgases would be effectively removed by a wet scrubbing system. The solid waste from the kiln would be detoxified and safe to handle for disposal.

The wastewater from this system may contain high concentrations of total dissolved solids (TDS). The environmental and health impacts of discharging streams containing non-hazardous dissolved solids depends on the receiving water body.

Details on the occupational and health effects for hydrogen chloride are given in Appendix I.

5.1.5.1.4 Costs for Detoxification of Metal Hydroxides by Calcination

a. Process Design and Cost Evaluation Bases

The fundamental design considerations used in estimating costs for this process are:

(1) Chromium hydroxide* bearing sludge from a typical 100 kkg/day titanium dioxide plant would be processed in the treatment plant at the rate of 117 kkg/hour (129 tons/hour), 24 hours per day and 7 days per week.

(2) The use of a polyelectrolyte coagulant, a thickener and a rotary vacuum filter would increase the solids content of this gelatinous hydroxide sludge to about 25% solids by weight.[79]

(3) The filter cake would be washed with 100 kkg (110 tons) per day of pure water to reduce the residual chlorides in the filter cake and minimize the formation of appreciable amounts of heavy metal chlorides in the succeeding calcination operation. Some HCl would still be formed in the kiln due to

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*This material is considered the hazardous constituent in the sludge hydrolysis of the NaCl at the high calcination temperatures. However, the exit gases from the kiln would be scrubbed and neutralized as part of this process.

(4) The 25% solids filter cake would be divided and fed to three rotary calciners (based on technology information transfer provided by Kaiser Corporation on hydrated alumina calcination)[96] to produce approximately 100 kkg/day (110 tons/day) of detoxified residue consisting of insoluble heavy metal oxides. Emissions from the calciners would be controlled by a combination of cyclone and wet scrubber systems with the scrubber liquor periodically purged to the calciner and the cyclone-collected particulate also recycled to the calciner.

(5) Approximately 2,300 kkg/day (2,535 tons/day) of waterborne waste would be generated from dewatering and cake washing. This waste would contain 200-500 mg/l of TSS and unknown but high concentrations of dissolved chlorides. This stream would be returned to the main plant waste treatment ponds.

b. Costing Methodology Used

The standard methodology discussed in Appendix II was used to develop costs for this treatment plant.

c. Cost Summary and Energy Requirement

The estimated total capital cost for system 07100 is $13,257,000. The system annual power and heat requirements are 3,270,000 kwh and 3.93×10^{11} kg cal (1.56×10^{12} BTU), respectively. The estimated unit operating costs are as follows:

$193/kkg ($175/ton) of titanium dioxide product
$138/kkg ($125/ton) of raw waste (dry basis)
$6.9/kkg ($6.2/ton) of raw waste (wet basis)

d. Detailed Process Equipment and Cost Information

Table 23 lists details on equipment size and operating conditions for this process. Total installed capital cost is shown in Table 24 and the annual operating cost breakdown for this plant is presented in Table 25.

5.1.6 Waste Stream 8, Wastewater Treatment Sludges - Chrome Color and Inorganic Pigment Manufacturing

Two conceptualized detoxification processes have been selected for treating wastewater treatment sludges from chrome color and inorganic pigment manufacturing. These are:

(1) detoxification of metal hydroxides by kaolin added calcination and
(2) detoxification of metal hydroxides by evaporation and asphalting.

Details on these processes are given below.

TABLE 23

SYSTEM 07100, EQUIPMENT NEEDS, SPECIFICATIONS AND OPERATING CONDITIONS

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
07101	1	1900 l/min (500 gpm) centrifugal sludge transfer pump - cast iron construction	Operates at 25° C (77° F) and head of approximately 30.48 m (100 ft.)
07102	1	18.3 m (60 ft) diameter thickener handles 2.7 MM liters/day (713,000 gpd) of sludge- mild steel construction	Operates at 25° C (77° F) and 1 atm. Produces 1.46 MM liters/day (387,000 gpd) of an underflow containing 9% solids and a clear overflow of 1.34 MM liters/day (327,000 gpd)
07103	1	3,800 liters (1,000 gal) floc slurry tank; holds approximately one day's supply of floc slurry (0.5% solution of Magnafloc 985 - Am. Cyanamid) - mild steel construction	Operates at 25° C (77° F) and 1 atm.
07104	1	1 HP SS turbine mixer	Operates at 25° C (77° F)
07105	1	3.8 l/min (1 gpm) floc slurry metering pump - stainless steel construction	Operates at 25° C (77° F) and head of approximately 30.48 m (100 ft.)
07106	1	960 l/min (250 gpm) thickener overflow centrifugal transfer pump - cast iron construction	Operates at 25° C (77° F) and head of approximately 30.48 m (100 ft.)
07107	1	1,160 l/min (300 gpm) centrifugal transfer pump - cast iron construction	Pumps a 9% slurry at 25° C (77° F) and total head of approximately 30.48 m (100 ft.)
07108	11	3.7 m (12 ft) diameter x 7.3 m (24 ft) long continuous rotary vacuum filter each with 84.7 sq m (912 sq ft) of filtering area - mild steel construction with polypropylene filter cloth	Operates at 58.42 cm (23 in) Hg vacuum and 25° C (77° F). Produces filter cake of 25% solids. Filter cake is washed to dilute entrained dissolved chlorides.

TABLE 23 (continued)

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
07109	11	760 l/min (200 gpm) centrifugal filtrate transfer pump - cast iron construction	Operates at 25° C (77° F) and total head of approximately 30.48 m (100 ft). Pumps combined filtrate and wash water to plant central storage pond system
07110	11	20 HP mechanical vacuum pump	Operates at 25° C (77° F). Draws operating vacuum or filter of 58.4 cm (23 in.) Hg
07111	11	76 l/min (20 gpm) centrifugal wash water pump - mild steel construction	Operates at 25° C (77° F) and total head of approximately 30.48 m (100 ft). Provides pure wash water to rotary vacuum filter
07112	3	39 cu m (1,400 cu ft) filter cake storage (hold 2 hrs. of filter cake production) - mild steel construction	Operates at 25° C (77° F)
07113	3	15 m (50 ft) rubber conveyor belt	Operates at 25° C (77° F)
07114	3	2.9 m (9.5 ft) diameter x 76 m (250 ft) long rotary calciners equipped with calcined product coolers discharging to screw feeders 07115 - mild steel, refractory-lined construction	Each unit processes 187 kkg/day (206 tons/day of 25% solids filter cake. Operates at maximum temperature of approximately 1,100° C (2,000° F). Heat utilization in the kiln is approximately 40%. Produces 100 kkg/day (110 tons) of calcined detoxified solids (insoluble heavy metal oxides) which are sent to a sanitary landfill
07115	3	8 kkg/hr (8.8 tons/hr) screw feeders - mild steel construction	Operates at 37°-66° C (100°-150° F)
07116	3	21 cu m (750 cu ft) detoxified solids product hold bin (holds 1 day's production) - mild steel construction	Operates at 25° C (77° F) and 1 atm.

TABLE 23 (continued)

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
07117	3	Cyclones - refractory lined mild steel construction	Handles 99,120 l/min (3,500 ACFM) at 204° C (400° F) at 1 atm. of flue gases containing 4.2 kkg/day (4.63 tons/day) of particulate. Gases consist of CO, CO_2, H_2O, N_2, and a small output of HCl. Outlet temperature of gases from this unit is 149° C (300° F). Unit removes about 85% of the particulate in the inlet stream which is recycled to the kiln
07118	3	42,500 l/min (1,500 CFM) high energy jet venturi scrubbers - stainless steel construction	Scrub gases with 378.5 l/min (100 gpm) of dilute caustic solution. Gases leave scrubber at about 66° C (150° F) and are vented. Residual particulate is essentially removed in these scrubbers (scrubber efficiency is 99.9%) as well as the small amount of HCl in the stream being neutralized by the caustic scrub solution. Approximately 2,270 l/day (600 gpd) of caustic scrubber liquor is purged from the system and recycled to the rotary calciner
07119	3	3,800 liters (1,000 gal) scrubber liquor surge tanks - mild steel construction	Operates at 25° C (77° F) and 1 atm.
07120	3	380 l/min (100 gpm) recirculated pump - cast iron construction	Operates at 25° C (77° F) and total head of approximately 378.5 m) 100 ft.
07121	3	71,000 l/min (2,500 CFM) induced draft fan - mild steel construction	Fan operates at about 66° C (150° F). Discharges < .04 kkg/day of particulate

TABLE 24

TREATMENT SYSTEM 07100 - TOTAL INSTALLED CAPITAL COST

Equipment No. & Description		Installed Cost
07101	sludge transfer pump	$ 2,500
07102	sludge thickener	149,000
07103	floc slurry feed tank	1,700
07104	turbine mixer	500
07105	floc slurry rotary pump	1,100
07106	thickener overflow transfer pump	2,000
07107	thickener underflow transfer pump	2,500
07108	rotary vacuum filter (11)	440,000
07109	filtrate transfer pump (11)	11,200
07110	mechanical vacuum pump (11)	160,600
07111	wash water pump (11)	4,400
07112	filter cake storage bin (3)	12,100
07113	conveyor belt (3)	26,000
07114	rotary calciner (3)	7,240,000
07115	calcined solids screw feeders (3)	12,000
07116	calcined solids hold bin (3)	14,400
07117	cyclone (3)	9,400
07118	venturi wet scrubber (3)	13,700
07119	scrub liquor surge tanks (3)	5,000
07120	scrub liquor recirculating pump (3)	3,800
07121	exhaust fan (3)	3,900
	Sub-total	8,115,800
Piping and Valve @ 25% of equipment		2,028,950
Building, 464.5 sq m @ $387/sq m (5,000 sq ft @ $36/sq ft)		180,000
	Sub total	$10,324,750
Engineering @ 7%		722,750
	Sub-total	$11,047,500
Contingency @ 20%		2,209,500
	Total Installed Capital Cost	$13,257,000

TABLE 25

ANNUAL OPERATING COSTS FOR TREATMENT SYSTEM 07100

CAPITAL INVESTMENT	\$13,257,000
VARIABLE COSTS	
Direct operating labor, 3 men/shift @ \$9/hr.	237,000
Supervision and Administrative @ 50% of direct operating labor	118,000
Maintenance @ 4% of capital investment	530,300
Power, 3,270,000 kwh @ 3¢ kwh	98,000
Fuel requirement, 3.93 x 10^{11} kg cal @ \$7.94/MM kg cal (1.56 x 10^{12} BTU @ \$2.00 MM BTU)	3,127,000
Sampling and Testing	30,000
Waste Disposal, 36,500 kkg @ \$6/kkg (40,223 tons @ \$5.44/kkg)	219,000
Total Variable Cost	\$4,359,300
FIXED COSTS	
Taxes and Insurance @ 4% of capital investment	530,300
Capital Recovery Rate (10 yrs. @ 10% equiv. to 0.1627/yr)	2,156,900
Total Fixed Cost	\$2,687,200
TOTAL OPERATING COST	\$7,046,500
Unit Costs	
\$/kkg (\$/ton) of titanium dioxide produced	193 (175)
\$/kkg (\$/ton) of raw waste (dry basis)	138 (125)
\$/kkg (\$/ton) of raw waste (wet basis)	6.89 (6.24)

5.1.6.1 Treatment Scheme 1 - Detoxification of Metal Hydroxides by Kaolin Added Calcination

5.1.6.1.1 Process Description and Material Balance

This waste stream is usually dewatered and ready for calcination. Kaolin clay would be added to the waste sludge to immobilize heavy metals present in the slag. This mixture would be conveyed to a rotary kiln where metal hydroxides and lead chromate are converted to oxides (lead chromate would be converted to lead and chrome oxides and ferric ferrocyanide would be converted to ferric oxide, carbon dioxide and NO_x). The product from the calciner would be detoxified and could be disposed of in a sanitary landfill. The gaseous emissions from the calciner may contain NO_x and particulates. Treatment by a cyclone followed by alkaline scrubbing should control particulate and NO_x emissions. The scrubber solution would be recycled with intermittent purges being fed to the calciner.

Figure 26 shows a detailed flow sheet and an approximated material balance for a treatment plant to process waste sludges generated by a typical 23 kkg/day pigment plant.

5.1.6.1.2 Application to Date

a. Full-Scale Treatment Installation

None known.

b. Laboratory and Pilot Plant Operations

There are no known pilot plants or laboratory investigations experimenting with this waste stream. However, all fundamental operations employed in this conceptual design are established unit processes. The process is believed to be technically feasible. Laboratory runs to optimize the processing conditions and a pilot plant to demonstrate the process would be required to validate this concept.

c. Pilot or Full-Scale Operations Treating Similar Wastes

A report concerning the application of kaolin added calcination to harmful waste sludges from a chromium plating process has been described in Proceedings of Japan Chemical Society, 8th Spring Meeting, Tokyo, Japan, April 1-5, 1973 (Solid Waste Information Retrieval System, Accession No. 028838). Experiments involved the preparation of three different samples (A, B & C) by diluting the air dried sludge containing 19.8 weight percent of chromium, 8.3 weight percent of nickel, 5.4 weight percent of calcium and 3.2 weight percent of copper with kaolin at a prescribed ratio of 1 to 0, 1 to 1, 1 to 2 and calcined at 800° to 900° C (1,471° to 1,651° F). Testing for the stabilization of the heavy metals was performed by dipping 1 gram of the calcined material in 100 ml of 1N ammonium acetate/acetic acid aqueous solution and analyzing for heavy metals concentration. It was generally concluded that the addition of kaolin to the sludge prior to calcination was effective for immobilization of heavy metals.

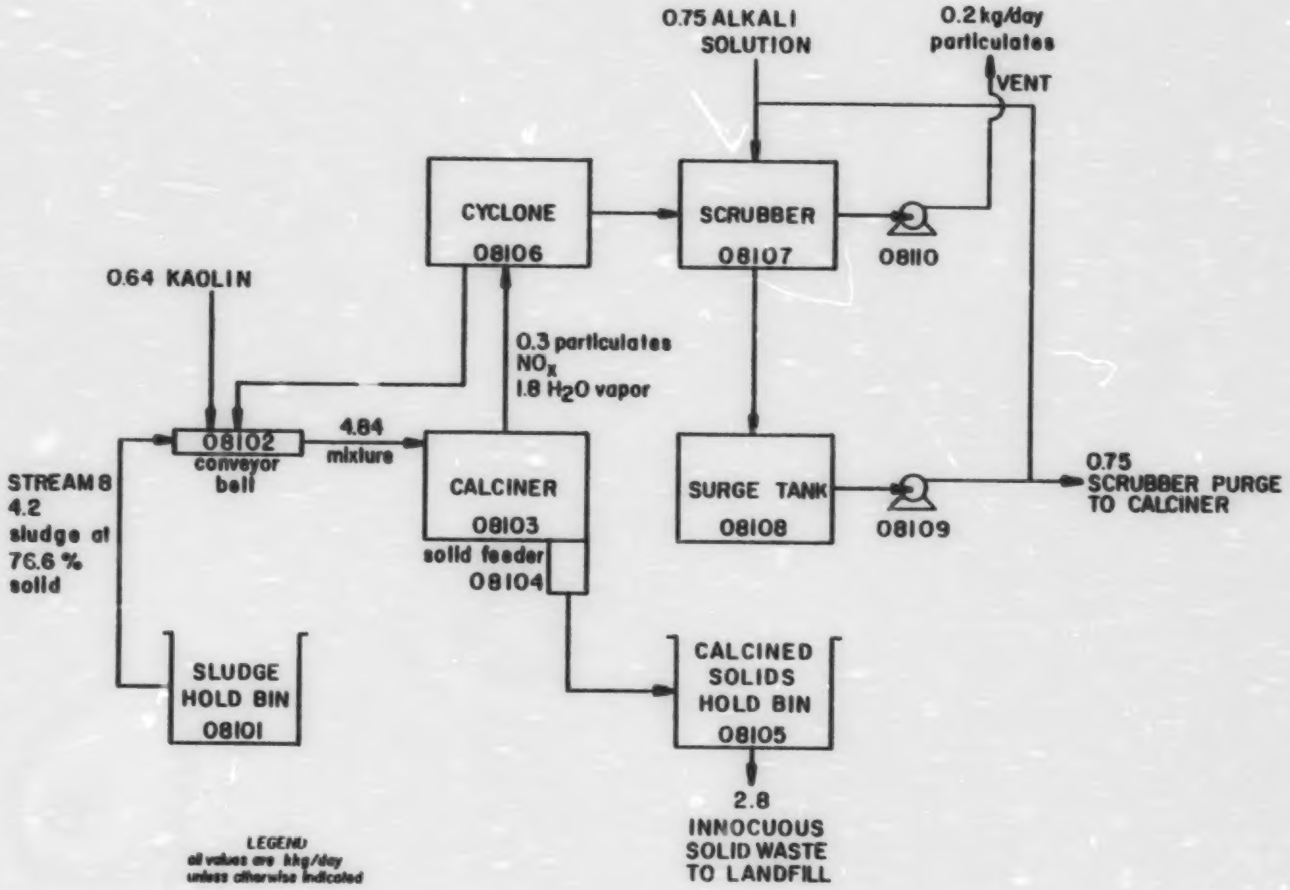
0.75 ALKALI SOLUTION
0.2 kg/day particulates
VENT
CYCLONE 08106
SCRUBBER 08107
08110
0.64 KAOLIN
0.3 particulates
NO_x
1.8 H_2O vapor
08102 conveyor belt
4.84 mixture
STREAM 8 4.2 sludge at 76.6 % solid
CALCINER 08103
solid feeder 08104
SURGE TANK 08108
08109
0.75 SCRUBBER PURGE TO CALCINER
SLUDGE HOLD BIN 08101
CALCINED SOLIDS HOLD BIN 08105
2.8 INNOCUOUS SOLID WASTE TO LANDFILL
LEGEND
all values are kkg/day
unless otherwise indicated

FIGURE 26 – DETOXIFICATION OF METAL HYDROXIDES BY CALCINATION (system 08100)

5.1.6.1.3 Benefits and Environmental Consequences

a. Benefit Analysis Information

The benefits resulting from the calcination of wastewater treatment sludges from chrome color and inorganic pigment manufacturing operations (stream 8) are:

(1) solid waste detoxification and
(2) solid waste volume reduction.

The major benefit achieved by this system is detoxification of hazardous components in the waste stream through conversion to their respective less soluble metal oxides. This system would also achieve a waste volume reduction for disposal resulting in an annual cost savings of about $2,180 (excluding treatment process costs).

A summary of the benefits achieved by this process is shown in column 7 of Table 8.

b. Environmental Impact

There are air emissions and solid wastes generated by this treatment process. However, these emissions and solid wastes presents a minimal threat to the environment and personnel safety. The only serious issue associated with this process is that the process is highly energy intensive.

Air Pollution

Limited quantities of air emissions would be released from the cyclone/scrubber system employed to control NO_x and particulate emissions. It is estimated that particulate emissions would be approximately 0.2 kg/day and the NO_x emissions would also be within applicable limitations.

Water Pollution

There are no waterborne wastes from this system.

Solid Waste

There would be approximately 3.4 kkg/day of detoxified solid waste generated by this system which could be disposed of in a sanitary landfill.

Safety & Health Aspects

There are no personnel and safety hazards associated with this treatment process. The particulate and NO_x in the calciner offgases would be controlled by a wet scrubbing system. The solid waste would be detoxified and present no adverse environmental effect.

Details on the occupational and health effects for NO_x gases are given in Appendix I.

5.1.6.1.4 Costs for Treatment System 1

a. Process Design and Cost Evaluation Bases

The fundamental design considerations used in estimated costs for this process are:

(1) Sludge containing heavy metal compounds from a typical 23 kkg/day (25.3 tons/day) chrome color and inorganic pigment manufacturing plant would be processed in this treatment plant at a rate of 0.53 kkg/hr (0.58 tons/hr), 8 hours per day, 5 days per week.

(2) The 4.2 kkg/day (4.63 tons/day) of sludge containing approximately 77% solids would be mixed with 0.64 kkg/day (0.71 tons/day) of kaolin, the mixture then would be fed to a rotary calciner. Maximum calcination temperature would be 900° C (1,653° F). The residue from calcination would be suitable for landfilling.

(3) The emissions from the calciner would be exhausted through a cyclone and wet scrubber system operating in series with probable emissions in the vent being <0.04 kg/kkg (<0.08 lb/ton) of calcined residue.

b. Costing Methodology Used

The standard methodology discussed in Appendix II was used to develop costs for this treatment plant.

c. Cost Summary and Energy Requirement

The estimated total capital cost for system 08100 is $1,066,000. The estimated annual power and heat requirements are 150,000 kwh and 1.58×10^9 kg cal (6.26×10^9 BTU), respectively.

The unit operating costs are as follows:

$45/kkg ($41/ton) of pigment products
$450/kkg ($408/ton) of raw waste (dry basis)
$342/kkg ($310/ton) of raw waste (wet basis)

d. Detailed Process Equipment and Cost Information

Table 26 lists details on equipment size and operating conditions for this process. Breakdowns of total capital cost and annual operating costs are shown in Table 27 and 28, respectively.

5.1.6.2 Treatment Scheme 2 - Detoxification of Metal Hydroxides by Evaporation and Asphalting

5.1.6.2.1 Process Description and Material Balance

The initial steps of the process involve mixing the waste sludge with commercial emulsified asphalt in an evaporator and raising the tempera-

TABLE 26

SYSTEM 08100, EQUIPMENT NEEDS, SPECIFICATIONS AND OPERATING CONDITIONS

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
08101	1	5.6 cu m (200 cu ft) sludge hold bin (holds 2 days supply of feed to treatment plant) - mild steel construction	Operates at 25° C (77° F) and 1 atm.
08102	1	15 m (50 ft) screw conveyor - mild steel construction	Operates at 25° C (77° F) and 1 atm. Ground kaolin is added to the sludge at the inlet of the screw conveyor at the rate of 0.64 kkg/day (0.705 tons/day).
08103	1	1.8 m (6 ft) diameter x 21.4 m (70 ft) rotary calciner including calcined solids cooler, drive, burner and controls - mild steel refractory-lined construction	Operates at a maximum temperature of 900° C (1,652° F) and 1 atm. Combustion gases flow countercurrent to solids. Exit gas temperature is about 204° C (400° F). Calcined solids leave kiln cooling equipment at about 93° C (200° F). Heat utilization in kiln is approximately 40%.
08104	1	6.1 m (20 ft) calcined solids screw conveyor	Discharges 2.8 kkg/day (3.09 tons/day) of calcined solids to hold bin 08105.
08105	1	2.8 cu m (100 cu ft) calcined solids bin (holds one day's production) - mild steel construction	Operates at an average temperature of 38° C (100° F) and 1 atm. Solids are discharged daily to trucks and taken to a sanitary landfill at the rate of 2.8 kkg/day (3.09 tons/day).
08106	1	8,500 l/min (300 CFM) cyclone - refractory lined, mild steel construction	Operates at a temperature of 204° C (400° F) and 1 atm. Recovers 0.24 kkg/day (0.26 tons/day) of particulate (75% efficiency) which is recycled to calciner.

TABLE 26 (continued)

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
08107	1	7,100 l/min (250 CFM) jet venturi scrubber - mild steel construction	Operates at an average temperature of 121° C (250° F) and 1 atm. Uses 37.85 l/min (10 gpm) of recirculating 5% caustic solution to absorb any NO_x in the gas stream and removes ~0.07 kkg/day (0.077 tons/day) of particulate (operates at 99% efficiency). Discharges <0.1 kg/day (0.22 lb/day) of particulate from vent)
08108	1	2,300 liters (600 gal) scrubber liquor surge tank (holds 1 hour's supply of 5% caustic mild steel construction	Operates at 25° C (77° F) and 1 atm.
08109	1	4,500 l/min (160 CFM) blower fan - cast iron construction	Operates at 38° C (100° F) and 1 atm. Discharges <0.1 kg/day (0.22 lb/day) particulate, water vapor and noncondensibles to atmosphere
08110	1	38 l/min (10 gpm) centrifugal recirculating pump - cast iron construction	Operates at 25° C (77° F) and total head of approximately 30.48 m (100 ft)

TABLE 27

TREATMENT SYSTEM 08100 - TOTAL INSTALLED CAPITAL COST

Equipment No. & Description	Installed Cost
08101 sludge hold bin	$ 2,200
08102 screw conveyor	6,000
08103 rotary calciner system	615,000
08104 screw conveyor	3,600
08105 calciner solids hold bin	1,600
08106 cyclone	2,400
08107 venturi scrubber	1,400
08108 surge tank	1,400
08109 blower	600
08110 recirculating pump	1,000
Sub-total	$635,200
Piping and Valves @ 25% of equipment	159,000
Building, 92.9 sq m @ $387/sq m (1,000 sq ft @ $36/sq ft)	36,000
Sub-total	$830,200
Engineering @ 7%	58,100
Sub-total	$888,300
Contingency @ 20%	177,700
Total Installed Capital Cost	$1,066,000

TABLE 28

ANNUAL OPERATING COSTS FOR TREATMENT SYSTEM 08100

CAPITAL INVESTMENT	$1,066,000
VARIABLE COSTS	
Treatment Chemicals 166 kkg Kaolin @ $160/kkg[17] (183 tons @ $145/ton)	26,500
Direct operating labor, 2 men/shift @ $9/hour	37,500
Supervision and Administrative, @ 50% of direct labor	18,750
Maintenance @ 4% of capital investment	42,600
Power, 150,000 kwh @ 3¢/kwh	4,500
Process Heat, 1.58×10^9 kg cal @ $7.94/MM kg cal ($6.26 \times 10^9$ BTU @ $2.00/MM BTU)	12,500
Sampling and Analysis	12,000
Waste Disposal 728 kkg @ $6.00/kkg (803 tons @ $5.44/ton)	4,400
Total Variable Cost	$158,750
FIXED COSTS	
Capital Recovery Rate (10 yrs. @ 10% equiv. to 0.1627/yr)	$173,400
Taxes and Insurance @ 4% of capital cost	42,600
Total Fixed Costs	$216,000
TOTAL ANNUAL OPERATING COST	$374,750
Unit Costs	
$/kkg ($/ton) of pigment products	45 (41)
$/kkg ($/ton) of raw waste (dry basis)	450 (408)
$/kkg ($/ton) of raw waste (wet basis)	342 (310)

ture to evaporate the water in the mix. The solids remain intimately dispersed in the asphalt and the product flows out the bottom of the evaporator into a receiving drum at 102° C to 106° C (250° to 320° F). Emulsified asphalt (35 wt. % water) would be used in this process because it flows readily at room temperature and is easily pumped.

The waste and asphalt would be introduced at the top of a wiped-film evaporator. The mixture would flow down the walls of the evaporator at about 160° C (320° F). Agitator paddles in the evaporator would sweep the walls continuously at about 100 RPM providing effective mixing and satisfactory heat transfer.

The water vapor from the evaporator would be condensed and collected in a suitable receiver for use at the plant.

Figure 27 shows a detailed flow sheet and material balance for a treatment plant to process waste sludges generated by a typical 23 kkg/day pigment plant.

5.1.6.2.2 Application [illegible] Date

a. Full-Scale Treatment Installation

None known

b. Laboratory and Pilot Plant Operations

There are no known pilot plants or laboratory investigations experimenting with this waste stream. However, wastes containing high concentrations of various inorganic compounds have been treated successfully by this process during laboratory tests at Oak Ridge National Laboratories. Laboratory tests and pilot plant demonstration with the subject waste stream would be required to optimize the processing conditions and validate this concept.

c. Pilot or Full-Scale Operations Treating Similar Wastes

This process has been successfully demonstrated in both continuous and batch mixing operations at Oak Ridge National Laboratory, Oak Ridge, Tennessee. Pilot plant tests were made with simulated radioactive waste in a 0.305m (12-inch) diameter by 0.406m (16-inch) long Pfaudler wiped-film evaporator with 0.372 sq m (4 sq ft) of heat transfer surface. This unit processed about 41.6 liters (11 gallons) of waste per hour and operated for 62 hours. No operating difficulties were encountered. The equipment operated satisfactorily with up to 64 weight percent of salts in the product. The wear of the wiper blades was negligible.

Inorganic or organic wastes that are to be incorporated in asphalt should be either neutral or alkaline. Incorporation of acid wastes or wastes containing large amounts of oxidants (e.g., nitrate) in asphalt is not recommended because acids degrade asphalt and the reactions of oxidants with asphalt could be hazardous. These waters can be incorporated in polyethylene, instead of asphalt.

The key contact on this process is Dr. H. W. Godbee at Oak Ridge National Laboratory, Oak Ridge, Tennessee.

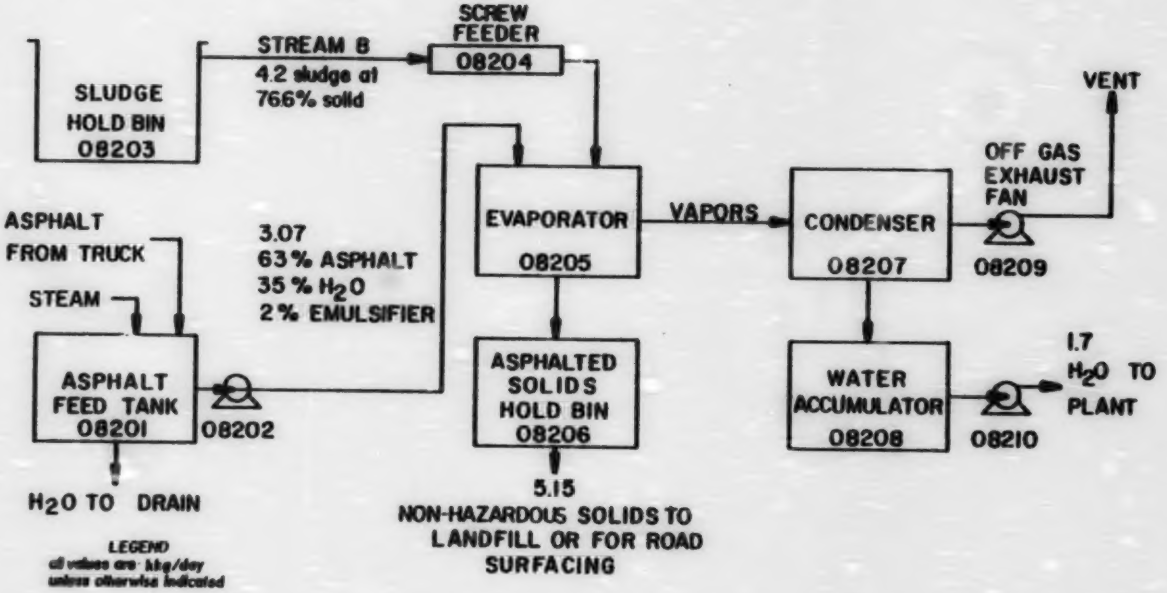
SLUDGE
HOLD BIN
08203
STREAM 8
4.2 sludge at
76.6% solid
SCREW
FEEDER
08204
ASPHALT
FROM TRUCK
STEAM
3.07
63% ASPHALT
35% H_2O
2% EMULSIFIER
ASPHALT
FEED TANK
08201
08202
H_2O TO DRAIN
LEGEND
all values are kkg/day
unless otherwise indicated
EVAPORATOR
08205
VAPORS
ASPHALTED
SOLIDS
HOLD BIN
08206
5.15
NON-HAZARDOUS SOLIDS TO
LANDFILL OR FOR ROAD
SURFACING
CONDENSER
08207
WATER
ACCUMULATOR
08208
OFF GAS
EXHAUST
FAN
08209
VENT
1.7
H_2O TO
PLANT
08210

FIGURE 27 - DETOXIFICATION OF METAL HYDROXIDES BY EVAPORATION AND ASPHALTING (system 08200)

5.1.6.2.3 Benefits and Environmental Consequences

a. Benefit Analysis Information

The benefits resulting from this operation are:

(1) solid waste detoxification and

(2) the production of a clean water distillate that can be either safely discharged or reused.

The resulting solid product, though approximately 40 percent greater in volume than the original sludge, can be disposed of in a sanitary landfill. A preferable disposition for this material would be to use it, either directly or combined with other insoluble aggregates such as limestone or sand, for road surfacing. This would help to reduce the need for new landfill areas.

A summary of the benefits achieved by this process is shown in column 8 of Table 8.

b. Environmental Impact

There is solid waste generated by this treatment process. However, this waste presents no threat to the environment and personnel safety. The relatively large energy requirements are of possible concern, but this may be a minor issue considering the relatively small volume of waste which would be treated by this system. The major issue of concern is the highly variable availability of asphalt throughout the U.S.A. Additionally asphalt may become scarce on a long-range basis due to the shortage of petroleum base feed stock.

Air Pollution

There are no air emission problems associated with this system. Water vapor from the evaporator would be condensed and collected.

Water Pollution

No waterborne waste is generated by this process.

Solid Waste

There would be approximately 5 kkg/day of detoxified solid material generated by this system.

Safety and Health Aspects

None

5.1.6.2.4 Costs for Treatment System 2 - Detoxification of Metal Hydroxides by Evaporation and Asphalting

a. Process Design and Cost Evaluation Bases

The fundamental design considerations used in estimating costs for this process are:

(1) Sludge containing the heavy metal compounds as generated in a typical 23 kkg/day (25.3 tons/day) chrome color and inorganic pigment manufacturing plant would be processed in this treatment plant at the rate of 0.53 kkg/hr (0.58 tons/hr), 8 hours per day and 260 days per year.

(2) The 4.2 kkg/day (4.6 tons/day) of sludge, containing approximately 77% solids would be fed to a wiped-film evaporator, together with 3.1 kkg/day (3.4 tons/day) of emulsified asphalt, the latter material consisting of 63 wt.% base asphalt, 35 wt.% water, and 2 wt.% emulsifier. In the evaporator which operates at 150° C (302° F), 2.1 kkg/day (2.3 tons/day) of water would be removed (essentially all of the water in the feed streams), producing 5.2 kkg/day (5.7 tons/day) of dry residue which consists of 62.5 wt.% solids and 37.5 wt.% asphalt. This material would be suitable for disposal to a sanitary landfill.

(3) Approximately 80% of the water removed in the wiped-film evaporator would be condensed and recycled to the pigment plant for reuse. The offgases from the evaporator are assumed to be essentially particulate free.

b. Costing Methodology Used

In costing this process, standard methodology was used as discussed in Appendix II except for the cost of a wiped-film evaporator. Current costs for this equipment were supplied by the Pfaudler Co.[67]

c. Cost Summary and Energy Requirement

The estimated total capital cost for system 08200 is $195,000. The annual power and process heat (steam) requirements are estimated as 39,000 kwh and 4.59×10^8 kg cal (1.82×10^9 BTU), respectively.

The estimated unit operating costs are as follows:

$22/kkg ($20/ton) of pigment products
$220/kkg ($200/ton) of raw waste (dry basis)
$167/kkg ($151/ton) of raw waste (wet basis)

d. Detailed Process Equipment and Cost Information

Table 29 lists details on equipment size and operating conditions for this process. Breakdowns of total capital cost and annual operating costs are shown in Tables 30 and 31, respectively.

TABLE 29

SYSTEM 08200, EQUIPMENT NEEDS, SPECIFICATIONS AND OPERATING CONDITIONS

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
08201	1	14 cu m (500 cu ft) emulsified asphalt storage tank equipped with steam coils (holds approximately 1 week's supply) - mild steel construction	Operates at approximately 130° C (266° F) and 1 atm. Steam keeps emulsified asphalt sufficiently fluid to be pumpable.
08202	1	7.57 l/min (2 gpm) gear pump - mild steel construction	Pumps 0.4 kkg/hr (0.44 tons/hr) hot emulsified asphalt from storage tank to wiped-film evaporator. Operates at approximately 50° C (122° F) and total head of approximately 30.5 m (100 ft)
08203	1	2.8 cu m (100 cu ft) sludge hold bin - mild steel construction	Operates at 25° C (77° F) and 1 atm.
08204	1	15.2 m (50 ft) screw feeder - mild steel construction	Operates at 25° C (77° F). Feeds 0.52 kkg/hr (0.57 tons/hr) of sludge to wiped-film evaporator
08205	1	Wiped-film evaporator system. 2.3 sq m (25 sq ft) evaporating surface - stainless steel construction	Processes 0.9 kkg/hr (0.99 tons/hr) of emulsified asphalt and sludge feed at 150° C (302° F) and 1 atm. Evaporates 0.27 kkg/hr (0.30 tons/hr) of water. Discharged solids from evaporator are suitable for landfilling
08206	1	4.2 cu m (150 cu ft) asphalted solids hold bin (holds 1 day's production of solids) - mild steel construction	Operates at 40° C (104° F) and 1 atm.
08207	1	3.7 sq m (40 sq ft) condenser - mild steel construction on shell, copper tubes	Condenses approximately 80% of water vapor leaving wiped-film evaporator [0.27 kkg (0.29 tons) H_2O per hr]. Condensate at about 40° C (104° F) drains to an accumulator

15

TABLE 29 (continued)

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
08208	1	380 liters (100 gal) water accumulator - mild steel construction	Operates at 40° C (104° F) and 1 atm.
08209	1	3.8 l/min (1 gpm) condensate pump - mild steel construction	Operates at 25° C (77° F) at total head of approximately 30.5 m (100 ft)
08210	1	850 l/min (30 ACFM) exhaust fan - mild steel construction	Operates at approximately 50° C (122° F) and 1 atm. Discharges water vapor and non-condensibles to atmosphere

TABLE 30

TREATMENT SYSTEM 08200 - TOTAL INSTALLED CAPITAL COST

Equipment No. & Description		Installed Cost
08201	asphalt storage tank	$ 4,000
08202	gear pump	2,500
08203	sludge hold bin	2,000
08204	screw feeder	3,600
08205	wiped-film evaporator system	72,000
08206	residue hold bin	1,600
08207	condenser	5,000
08208	accumulator	500
08209	condensate pump	1,000
08210	exhauster	500
	Sub-total	$92,700
Piping and Valves @ 25%		23,200
Building, 92.9 sq m @ $387/sq m (1,000 sq ft @ $36/sq ft)		36,000
	Sub-total	$151,900
Engineering @ 7%		10,600
	Sub-total	$162,500
Contingency @ 20%		32,500
	Total Installed Capital Cost	$195,000

TABLE 31

ANNUAL OPERATING COSTS FOR TREATMENT SYSTEM 08200

CAPITAL INVESTMENT	$195,000
VARIABLE COSTS	
Asphalt, 837,700 liters @ 10.6¢/l (222,000 gal @ 40¢/gal)[81]	88,800
Direct operating labor, 1 man/shift @ $9/hr	18,750
Supervision and Administrative, @ 50% of direct operating labor	9,375
Maintenance @ 4% of capital investment	7,800
Power, 39,000 kwh @ 3¢/kwh	1,200
Process steam. 4.59×10^8 kg cal @ $15.87/MM kg cal ($1.82 \times 10^9$ BTU @ $4.00/MM BTU)	7,200
Sampling and Analysis	3,000
Waste Disposal, 1,350 kkg @ $6/kkg (1,488 tons @ $5.44/ton)	8,100
Total Variable Cost	$144,225
FIXED COSTS	
Capital Recovery Rate (10 yrs. @ 10% equiv. to 0.1627/yr)	31,800
Taxes and Insurance @ 4% of Capital Cost	7,800
Total Fixed Costs	$39,600
TOTAL OPERATING COST	$183,825
Unit Costs	
$/kkg ($/ton) of pigment products	22 (20)
$/kkg ($/ton) of raw waste (dry basis)	220 (200)
$/kkg ($/ton) of raw waste (wet basis)	167 (151)

5.1.7 Waste Stream 9, Gypsum Waste Sludges - HF Acid Manufacture

A conceptualized detoxification process consisting of evaporation and asphalting has been selected for treating gypsum wastes containing calcium fluoride from hydrofluoric acid manufacturing plants.

5.1.7.1 Detoxification of Calcium Fluoride Bearing Sludges by Evaporation and Asphalting

5.1.7.1.1 Process Description and Material Balance

This process has been described in detail in subsection 5.1.6.2.1 of this report. It involves the mixing of the waste sludge with commercial emulsified asphalt in an evaporator and raising the temperature to evaporate the water in the mix. The solids remain intimately dispersed in the asphalt and the product flows out the bottom of the evaporator.

Figure 28 shows a detailed flow sheet and material balance for a treatment plant to process gypsum wastes generated by a typical 64 kkg/day plant.

5.1.7.1.2 Application to Date

a. Full-Scale Treatment Installation

None known

b. Laboratory and Pilot Plant Operations

There are no known pilot plant or laboratory operations experimenting with this waste stream. However, fluoride containing wastes from the phosphate industry have been treated successfully by this process during laboratory tests at Oak Ridge National Laboratories. Laboratory tests and pilot plant demonstration with the subject waste stream would be required to optimize the processing conditions and validate this concept.

c. Pilot or Full-Scale Operations Treating Similar Wastes

This is discussed in detail in subsection 5.1.6.2.2c.

5.1.7.1.3 Benefits and Environmental Consequences

a. Benefit Analysis Information

The benefits resulting from this operation are:

(1) solid waste detoxification and
(2) the production of a clean water distillate that can be either safely discharged or reused.

The resulting solid product, though approximately 50 percent greater in volume than the original sludge, can be disposed of in a sanitary landfill. A preferable disposition for this material would be to use it, either directly or combined with other insoluble aggregates such as limestone or sand, for road surfacing. This would help to reduce the need for new landfill areas.

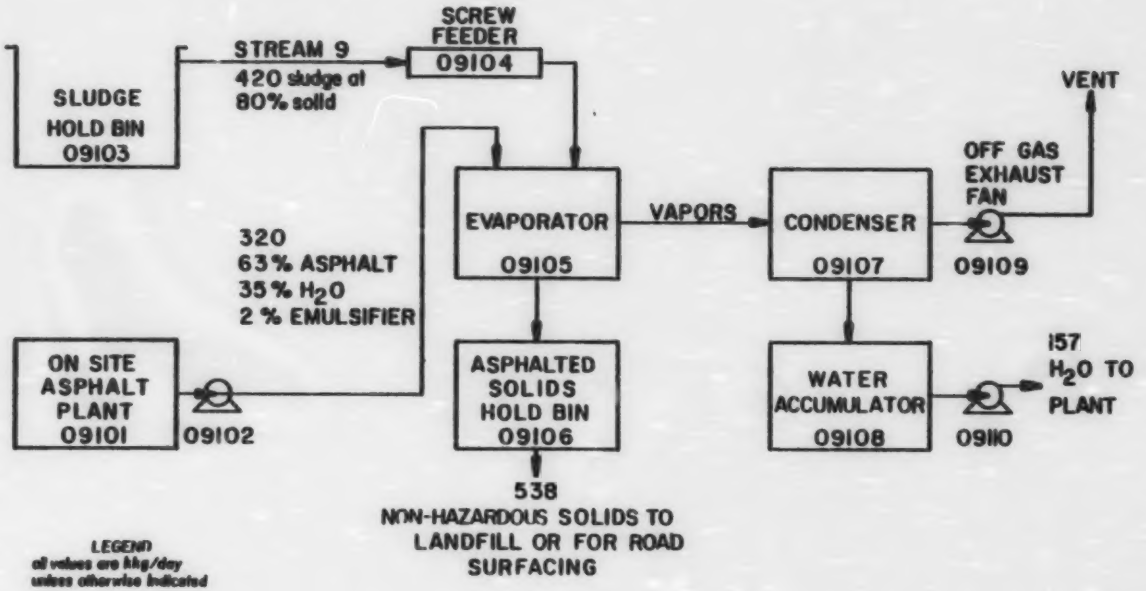
SLUDGE HOLD BIN 09103
STREAM 9
420 sludge at 80% solid
SCREW FEEDER 09104
EVAPORATOR 09105
VAPORS
CONDENSER 09107
OFF GAS EXHAUST FAN
09109
VENT
320
63% ASPHALT
35% H_2O
2 % EMULSIFIER
ON SITE ASPHALT PLANT 09101
09102
ASPHALTED SOLIDS HOLD BIN 09106
538
NON-HAZARDOUS SOLIDS TO LANDFILL OR FOR ROAD SURFACING
WATER ACCUMULATOR 09108
09110
157
H_2O TO PLANT
LEGEND
all values are kkg/day unless otherwise indicated

FIGURE 28 - TREATMENT OF GYPSUM WASTE CONTAINING CALCIUM FLUORIDE BY EVAPORATION AND ASPHALTING (SYSTEM 09100)

A summary of the benefits achieved by this process is shown in column 9 of Table 8.

b. Environmental Impact

Clean water and solid waste are generated by this treatment process. The solid waste presents no threat to the environment and personnel safety. The major issues of concern associated with this system are: (1) The system is highly energy intensive due to the large volume of water which has to be evaporated, (2) the volume of asphalt required is extremely large because of the large volume of waste sludge generated. These facilities would have to produce asphalt on-site. Raw materials to manufacture asphalt may become scarce because of the shortage of petroleum, and (3) there would be a constant need for new landfill areas if the product is proven to be unsuitable for use as aggregate.

Air Pollution

There are no emission problems associated with this system. Water vapor from the evaporator would be condensed and collected.

Water Pollution

No waterborne waste is generated by this process.

Solid Waste

There would be 538 kkg/day of non-hazardous solid waste generated by this system.

Safety and Health Aspects

None.

5.1.7.1.4 Costs for Detoxification of Calcium Fluoride Bearing Sludges by Evaporation and Asphalting

a. Process Design and Cost Evaluation Bases

The fundamental design considerations used in estimating costs for this process are:

(1) Calcium fluoride bearing gypsum sludge from a typical 64 kkg/day (70.5 tons/day) hydrofluoric acid plant, would be processed in the treatment plant at the rate of 17.5 kkg/hr (19.3 tons/hr), 24 hours per day, 5 days per week basis. The sludge contains 2.3 per cent by weight calcium fluoride (wet basis).

(2) The 420 kkg/day (463 tons/day) of sludge containing approximately 80% solids would be fed to wiped-film evaporators together with 320 kkg/day (353 tons/day) of emulsified asphalt. In the evaporation step which operates at 150° C, approximately 197 kkg/day (217 tons/day) of water would be removed (essentially all of the water in the two feed streams). The evaporators would produce 538 kkg/day (593 tons/day) of dry residue consisting of 62.5 wt.% waste solids and 37.5 wt.% asphalt. The material would be suitable for disposal in a sanitary landfill.

(3) The 320 kkg/day (353 tons/day), [approximately 341,000 l/day (90,000 gpd)] of emulsified asphalt would be prepared in an asphalt manufacturing plant on premises.

(4) Approximately 80% of the water removed in the wiped-film evaporation step would be condensed and recycled to the hydrofluoric acid plant for reuse. The offgases from the evaporator are assumed to be essentially particulate free.

b. Costing Methodology Used

Costing methodology used is the same as discussed in Section 5.1.6.2.4b, with the exception that costs for an asphalt plant (investment and operating) were obtained from a manufacturer of this equipment.

c. Cost Summary and Energy Requirement

The estimated total capital cost for system 09100 is $2,691,000. The estimated annual system power and process heat (steam) requirements are 900,000 kwh and 5×10^{10} kg cal (2×10^{11} BTU), respectively.

The estimated unit operating costs are as follows:

$360/kkg ($326/ton) of hydrofluoric acid product
$96/kkg ($87/ton) of raw waste (dry basis)
$77/kkg ($70/ton) of raw waste (wet basis)

d. Detailed Process Equipment and Cost Information

Table 32 lists details on equipment size and operating conditions for this process. Total capital cost is presented in Table 33 and an annual operating cost breakdown is presented in Table 34.

5.1.8 Waste Stream 11, Wastewater Treatment Sludges - Aluminum Fluoride Manufacture

A conceptualized detoxification process consisting of evaporation and asphalting has been selected for treating wastewater treatment sludges containing calcium fluoride from aluminum fluoride manufacturing operations.

5.1.8.1 Detoxification of Calcium Fluoride Bearing Sludges by Evaporation and Asphalting

5.1.8.1.1 Process Description and Material Balance

This process has been described in detail in subsection 5.1.6.2.1 of this report.

Figure 29 shows a flow sheet and material balance for a treatment plant to process calcium fluoride bearing wastes generated by a typical 145 kkg/day aluminum fluoride plant.

TABLE 32

SYSTEM 09100, EQUIPMENT NEEDS, SPECIFICATIONS AND OPERATING CONDITIONS

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
09101	1	380,000 l/day (100,000 gpd) emulsified asphalt manufacturing plant*	Produces 320 kkg/day (353 tons/day) of emulsified asphalt at 132° C (275° F)
09102	3	284 l/min (75 gpm) gear pump - stainless steel construction	Operates at 135°C (275°F) and approximate total head of 30.5 m (100 ft.) Pumps hot asphalt from storage tank to wiped-film evaporators
09103	3	84 cu m (3000 cu ft) sludge hold bins - mild steel construction	Operates at 25° C (77° F) and 1 atm.
09104	3	15 m (50 ft) screw feeders - mild steel construction	Feeds a total of 17.5 kkg/hr (19.3 tons/day) of gypsum sludge to wiped-film evaporators
09105	3	215 sq m (231 sq ft) wiped-film evaporator system - stainless-clad mild steel construction	Each evaporator processes 10.3 kkg/hr (11.4 tons/day) of emulsified asphalt and sludge feed at 150° C (302° F) and 1 atm. Each evaporator removes 2.7 kkg/hr of water. Discharged solids are suitable for landfilling
09106	3	140 cu m (5000 cu ft) asphalted solids hold bin (hold 1 day's production) - mild steel construction	Operates at 40° C (104° F) and 1 atm. Asphalted solids are loaded from bin into dump trucks and hauled to a landfill
09107	3	33 sq m (360 sq ft) condensers - mild steel construction shell, copper tubes	Condenses approx. 80% of water vapor leaving wiped-film evaporators (2.2 kkg/hr (2.42 tons/hr) of condensate per condenser). Condensate at about 40° C (104° F) drains to accumulator
09108	3	1,900 liters (500 gal) water accumulator - mild steel construction	Operates at 40° C (104° F) and 1 atm.

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* Includes colloid mill and drive, 3 pumps and drives, emulsifier preparation tank, 1-18,950 liter (5000 gal.) mix tank, 2-75,800 liter (20,000 gal) oil storage tanks, and 3-378,500 liter (100,000 gal.) finished asphalt storage tanks.

TABLE 32 (continued)

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
09109	3	42,500 l/min (1,500 CFM) exhaust fans - mild steel construction	Operates at 50° C (122° F) and 1 atm.
09110	3	38 l/min (10 gpm) centrifugal condensate recycle pump - cast iron construction	Operates at 50° C (122° F) and total head of approximately 30.5 m (100 ft)

TABLE 33

TREATMENT SYSTEM 09100 - TOTAL INSTALLED CAPITAL COST

Equipment No. & Description	Installed Cost
09101 asphalt plant	$ 470,000*
09102 asphalt transfer pump (3)	28,400
09103 sludge hold bins (3)	21,000
09104 sludge screw feeder (3)	21,600
09105 wiped-film evaporator system (3)	1,050,000
09106 asphalted solids hold bin (3)	48,000
09107 condenser (3)	55,000
09108 water accumulator (3)	4,100
09109 exhaust fans (3)	3,600
09110 condensate recycle pump (3)	3,000
Sub-total	$1,704,700
Piping and Valves (excluding asphalt plant) @ 25%	319,250
Building, 185.8 sq m @ $387/sq m) (2000 sq ft @ $36/sq ft)	72,000
Sub-total	$2,095,950
Engineering @ 7%	146,700
Sub-total	$2,242,650
Contingency @ 20%	448,500
Total Installed Capital Cost	$2,691,150

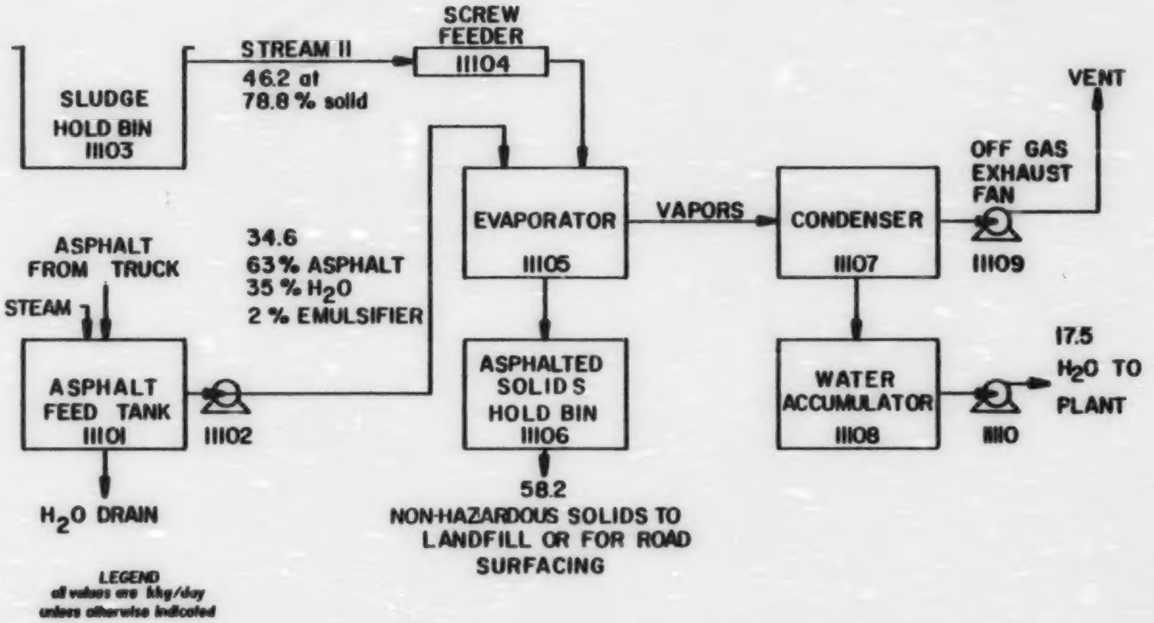
---

* The cost of the asphalt plant was obtained from Mr. Spark, K. E. McConnaughay, Inc., Lafayette, Indiana

TABLE 34

ANNUAL OPERATING COSTS FOR TREATMENT SYSTEM 09100

CAPITAL INVESTMENT	$2,691,150
VARIABLE COSTS	
Chemicals cost for manufacturing 8.7 x 10^7 liter emulsified asphalt @ 6.6¢/l[81] (23 MM gal @ 25¢/gal)	5,750,000
Direct operating labor, 4 men/shift @ $9/hr.	225,000
Supervision and Administrative @ 50% of direct labor	112,500
Maintenance @ 4% of capital investment	107,600
Power, 900,000 kwh @ 3¢/kwh	27,000
Process steam, 5 x 10^{10} kg cal @ $15.87/MM kg cal (2 x 10^{11} BTU @ $4.00/MM BTU)	800,000
Sampling and Analysis	15,000
Waste Disposal, 140,000 kkg @ $6/kkg (154,280 tons @ $5.44/ton)	840,000
Total Variable Costs	$7,877,100
FIXED COSTS	
Capital Recovery Rate (10 yrs. @ 10% equiv. to 0.1627/yr)	437,850
Taxes and Insurance @ 4% of Capital Cost	107,600
Total Fixed Costs	$545,450
TOTAL OPERATING COST	$8,422,550
Unit Costs	
$/kkg ($/ton) of hydrofluoric acid product	360 (326)
$/kkg ($/ton) of raw waste (dry basis)	96 (87)
$/kkg ($/ton) of raw waste (wet basis)	77 (70)



SLUDGE HOLD BIN 11103
STREAM 11
46.2 at 78.8 % solid
SCREW FEEDER 11104
EVAPORATOR 11105
VAPORS
CONDENSER 11107
OFF GAS EXHAUST FAN
11109
VENT
ASPHALT FROM TRUCK
STEAM
ASPHALT FEED TANK 11101
11102
34.6
63% ASPHALT
35 % H_2O
2 % EMULSIFIER
ASPHALTED SOLIDS HOLD BIN 11106
58.2
NON-HAZARDOUS SOLIDS TO LANDFILL OR FOR ROAD SURFACING
WATER ACCUMULATOR 11108
1110
17.5
H_2O TO PLANT
H_2O DRAIN
LEGEND
all values are kkg/day
unless otherwise indicated

FIGURE 29 - TREATMENT OF CALCIUM FLUORIDE BEARING SLUDGES BY EVAPORATION AND ASPHALTING (system 11100)

5.1.8.1.2 Application to Date

a. Full-Scale Treatment Installation

Non known.

b. Laboratory and Pilot Plant Operations

This has been discussed in subsection 5.1.7.1.2b.

c. Pilot Plant of Full-Scale Operations Treating Similar Wastes

This is discussed in detail in subsection 5.1.6.2.2c.

5.1.8.1.3 Benefits and Environmental Consequences

a. Benefit Analysis Information

The benefits resulting from this operation are:

(1) solid waste detoxification and
(2) the production of a clean water distillate that can be either safely discharged or reused.

The resulting solid product, though approximately 50 percent greater in volume than the original sludge, can be disposed of in a sanitary landfill.

A summary of the benefits achieved by this process is shown in column 10 of Table 8.

b. Environmental Impact

Clean water and solid waste are generated by this treatment process which present no threat to the environment and personnel safety. The major issues of concern, associated with this system, are: (1) it is energy intensive, (2) the highly variable availability of asphalt throughout the nation, and (3) there would be a constant need for new landfill areas if the product is proven to be unsuitable for use as aggregate.

Air Pollution

There are no emission problems associated with this system. Water vapor from the evaporator would be condensed and collected.

Water Pollution

No waterborne waste is generated by this process.

Solid Waste

There would be approximately 58 kkg/day of non-hazardous solid material generated by this system.

Safety and Health Aspects

None

5.1.8.1.4 Costs for Detoxification of Calcium Fluoride Bearing Wastewater Treatment Sludge by Evaporation and Asphalting

a. Process Design and Cost Evaluation Bases

The fundamental design considerations used in estimating costs for this process are:

(1) Calcium fluoride bearing wastewater treatment sludge from a typical 145 kkg/day (160 tons/day) aluminum fluoride plant would be processed in the treatment plant at the rate of 1.93 kkg/hr, (2.13 tons/hr) 24 hours per day and 260 days per week. The sludge contains 36 percent by weight calcium fluoride (wet basis).

(2) The 46.2 kkg/day (50.9 tons/day) of sludge containing approximately 79% solids would be fed to a wiped-film evaporator together with 34.6 kkg/day (38.1 tons/day) of emulsified asphalt. In the evaporation step, which operates at 150° C (302° F), approximately 22 kkg/day (24.2 tons/day) of water would be removed (essentially all of the water in the two feed streams). The evaporator would produce 58.2 kkg/day (64.1 tons/day) of dry residue which would be suitable for disposal in a sanitary landfill.

(3) Approximately 80% of the water removed in the wiped-film evaporator would be condensed and recycled to the aluminum fluoride plant for reuse. The offgases from the evaporator are assumed to be essentially particulate free.

b. Costing Methodology Used

Costing methodology used is the same as discussed in Section 5.1.6.2.4b.

c. Cost Summary and Energy Requirement

The estimated total capital cost for system 11100 is $261,000. The estimated annual power and process heat (steam) requirements are 120,000 kwh and 5×10^9 kg cal (2×10^{10} BTU), respectively.

The estimated unit operating costs are as follows:

$17/kkg ($15/ton) of aluminum fluoride product
$94/kkg ($185/ton) of raw waste (dry basis)
$74/kkg ($67/ton) of raw waste (wet basis)

d. Detailed Process Equipment and Cost Information

Table 35 lists details on equipment size and operating conditions for this process. Breakdowns of total installed capital cost and annual operating costs are shown in Tables 36 and 37 respectively.

TABLE 35

SYSTEM 11100, EQUIPMENT NEEDS, SPECIFICATIONS AND OPERATING CONDITIONS

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
11101	1	76,000 liters (20,000 gal) emulsified asphalt storage tank equipped with internal steam coils (holds 1 week's supply of asphalt) - mild steel construction	Operates at 135° C (275° F) and 1 atm.
11102	1	15 l/min (4 gpm) emulsified asphalt transfer pump (gear pump) - stainless steel construction	Operates at 135° C (275° F) and total head of approximately 30.5 m (100 ft.)
11103	1	28 cu m (1,000 cu ft) sludge hold tank - mild steel construction	Operates at 25° C (77° F) and 1 atm.
11104	1	15 m (50 ft) screw feeder - mild steel construction	Feeds 1.9 kkg/hr (2.09 tons/hr.) from hold tank to wiped-film evaporator
11105	1	15 sq m (50 sq ft) wiped-film evaporator system - stainless steel construction	Processes a total of 3.4 kkg/hr (3.75 tons/hr) of emulsified asphalt and sludge feed at 150° C and 1 atm. Removes 0.9 kkg/hr (0.99 tons/hr) of water. Discharged dry asphalted solids are suitable for landfilling
11106	1	42 cu m (1,500 cu ft) asphalted solids hold bin (holds 1 day's production) - mild steel construction	Operates at 40° C (104° F) and 1 atm. Asphalted solids are loaded daily into trucks and hauled to a landfill
11107	1	23 sq m (75 sq ft) condenser - mild steel construction on shell, copper tubes	Condenses approximately 80% of water vapor leaving wiped-film evaporator (0.7 kkg/hr (0.77 tons/hr) of condensate). Condensate at about 40° C (104° F) drains to an accumulator
11108	1	760 liters (200 gal) water accumulator - mild steel construction	Operates at 40° C (104° F) and 1 atm.

TABLE 35 (continued)

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
11109	1	21,000 l/min (750 CFM) exhaust fan - mild steel construction	Operates at 50° C (122° F) and 1 atm. Discharges water vapor and non-condensables to atm.
11110	1	15 l/min (4 gpm) centrifugal condensate recycle pump - cast iron construction	Operates at 40° C (104° F) and total head of approximately 30.5 m (100 ft)

TABLE 36

TREATMENT SYSTEM 11100 - TOTAL INSTALLED CAPITAL COST

Equipment No. & Description		Installed Cost
11101	emulsified asphalt storage tank	$ 25,000
11102	emulsified asphalt transfer pump	1,100
11103	sludge hold tank	5,900
11104	sludge screw feeder	3,000
11105	wiped-film evaporator system	82,000
11106	asphalted solids hold bin	7,000
11107	condenser	7,000
11108	accumulator	800
11109	exhaust fan	800
11110	condensate recycle pump	1,000
	Sub-total	$133,600
Piping and Valves @ 25%		33,400
Building 92.9 sq m @ $387/sq m (1,000 sq ft @ $36/sq ft)		36,000
	Sub-total	$203,000
Engineering @ 7%		14,200
	Sub-total	$217,200
Contingency @ 20%		43,400
	Total Installed Capital Cost	$260,600

TABLE 37

ANNUAL OPERATING COSTS FOR TREATMENT SYSTEM 11100

CAPITAL INVESTMENT	$260,600
VARIABLE COSTS	
Asphalt, 4,466,000 liters @ 10.6¢/l (1,180,000 gal @ 40¢/gal)	472,000
Direct operating labor, 2 men/shift @ $9/hr	112,300
Supervision and Administrative @ 50% of direct operating labor	56,150
Maintenance @ 4% of capital investment	10,400
Power, 120,000 kwh @ 3¢/kwh	3,600
Process steam, 5 x 10^9 kg cal @ $15.87/MM kg cal (2 x 10^{10} BTU @ $4.00/MM BTU)	80,000
Sampling and Analysis	15,000
Waste Disposal, 15,150 kkg @ $6/kkg (16,695 tons @ $5.44/ton)	91,000
Total Variable Costs	$840,450
FIXED COSTS	
Capital Recovery Rate (10 yr. @ 10% equiv. to 0.1627/yr)	42,400
Taxes and Insurance @ 4% of capital investment	10,400
Total Fixed Costs	$52,800
TOTAL OPERATING COSTS	$ 893,250
Unit Costs	
$/kkg ($/ton) of aluminum fluoride product	17 (15)
$/kkg ($/ton) of raw waste (dry basis)	94 (85)
$/kkg ($/ton) of raw waste (wet basis)	74 (67)

5.1.9 Waste Stream 13, Wastewater Treatment Sludges - Sodium Silicofluoride Manufacture

A conceptualized detoxification process consisting of evaporation and asphalting has been selected for treating calcium fluoride containing wastewater treatment sludges from sodium silicofluoride manufacturing operations.

5.1.9.1 Detoxification of Calcium Fluoride Bearing Sludges by Evaporation and Asphalting

5.1.9.1.1 Process Description and Material Balance

This process has been described in detail in subsection 5.1.6.2.1 of this report.

Figure 30 shows a flow sheet and material balance for a treatment plant to process calcium fluoride bearing wastes generated by a typical 45 kkg/day sodium silicofluoride plant.

5.1.9.1.2 Application to Date

a. Full-Scale Treatment Installation

None known

b. Laboratory and Pilot Plant Operation

This has been discussed in subsection 5.1.7.1.2b.

c. Pilot Plant or Full-Scale Operations Treating Similar Wastes

This was discussed in detail in subsection 5.1.6.2.2c.

5.1.9.1.3 Benefits and Environmental Consequences

a. Benefit Analysis Information

The benefits resulting from this operation are:

(1) solid waste detoxification
(2) solid waste reduction and
(3) the production of a clean water distillate that can be either safely disposed of or reused.

The treatment plant would achieve an annual cost savings of $25,750 resulting from the volume reduction of land destined wastes (excluding treatment process costs). Additionally, the solid waste would be intimately dispersed in the asphalt and the product could be safely disposed of in a sanitary landfill.

A summary of the benefits achieved by this process is shown in column 11 of Table 8.

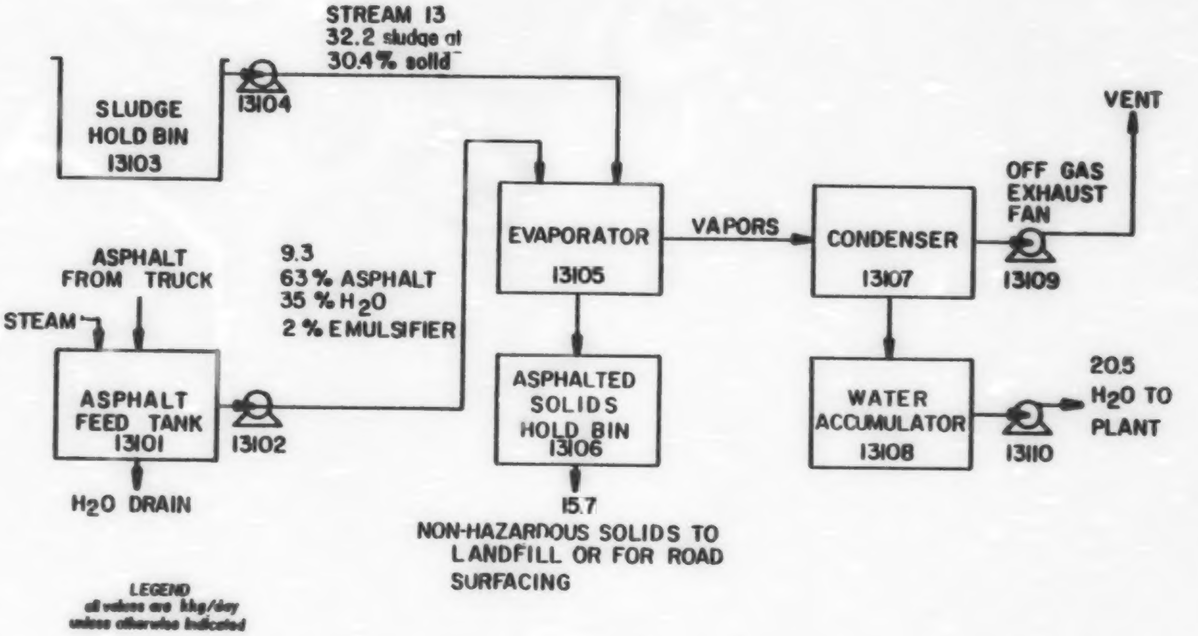

STREAM 13
32.2 sludge at
30.4% solid
SLUDGE
HOLD BIN
13103
13104
ASPHALT
FROM TRUCK
STEAM
ASPHALT
FEED TANK
13101
13102
H2O DRAIN
9.3
63% ASPHALT
35% H2O
2% EMULSIFIER
EVAPORATOR
13105
VAPORS
ASPHALTED
SOLIDS
HOLD BIN
13106
15.7
NON-HAZARDOUS SOLIDS TO
LANDFILL OR FOR ROAD
SURFACING
CONDENSER
13107
OFF GAS
EXHAUST
FAN
13109
VENT
WATER
ACCUMULATOR
13108
13110
20.5
H2O TO
PLANT
LEGEND
all values are kkg/day
unless otherwise indicated

FIGURE 30 – TREATMENT OF CALCIUM FLUORIDE BEARING WASTES BY EVAPORATION & ASPHALTING (system 13100)

b. Environmental Impact

Clean water and solid waste are generated by this treatment process which presents no threat to the environment and personnel safety. The major issues of concern associated with this system, are: (1) it is energy intensive because of the large volume of water required to evaporate and (2) the highly variable availability of asphalt throughout the nation. Additionally, asphalt may become scarce in the future because of the shortage of petroleum.

Air Pollution

There are no air emission problems associated with this system. Water vapor from the evaporator would be condensed and collected.

Water Pollution

No waterborne waste is generated by this process.

Solid Waste

There would be approximately 16 kkg/day of detoxified solid material generated by this system.

Safety and Health Aspects

None.

5.1.9.1.4 Costs for Detoxification of Calcium Fluoride Bearing Wastewater Treatment Sludge by Evaporation and Asphalting

a. Process Design and Cost Evaluation Bases

The fundamental design considerations used in estimating costs for this process are:

(1) Calcium fluoride bearing wastewater treatment sludge from a 45 kkg/day (50 tons/day) sodium silicofluoride plant, would be processed in the treatment plant at the rate of 1.34 kkg/hr (1.47 tons/hr), 24 hours per day, 260 days per year. Calcium fluoride is present in the range of 11-20% by weight (wet basis).

(2) The 32.2 kkg/day (35.5 tons/day) of sludge containing approximately 31% solids would be pumped to a wiped-film evaporator together with 9.3 kkg/day (10.2 tons/day) of emulsified asphalt. In the evaporator which operates at 150° C (302° F), approximately 25.6 kkg/day (28.2 tons/day) of water would be removed (essentially all of the water in the two feed streams). The evaporator would produce 15.7 kkg/day (17.3 tons/day) of dry residue which would be suitable for disposal in a sanitary landfill.

(3) Approximately 80% of the water removed in the wiped-film evaporator would be condensed and recycled to the sodium silicofluoride plant for reuse. The offgases from the evaporator are assumed to be essentially particulate free.

b. Costing Methodology Used

The costing methodology used is the same as discussed in Section 5.1.6.2.4b.

c. Cost Summary and Energy Requirement

The estimated total capital cost for system 13100 is \$383,000. The estimated annual power and heat (steam) requirements are 140,000 kwh and 3.78 x 10^9 kg cal (1.5 x 10^{10} BTU), respectively.

The estimated unit operating costs are as follows:

\$38/kkg (\$34.5/ton) of sodium silicofluoride product
\$247/kkg (\$224/ton) of raw waste (dry basis)
\$75/kkg (\$68/ton) of raw waste (wet basis)

d. Detailed Process Equipment and Cost Information

Table 38 lists details on equipment size and operating conditions for this process. Breakdowns of total installed capital cost and annual operating costs are shown in Tables 39 and 40, respectively.

5.1.10 Waste Stream 14 - Chromate Contaminated Wastewater Treatment Sludges - Chromate Manufacture

A conceptual process design has been prepared for a treatment plant to detoxify the hazardous components in this waste stream by calcination. Details on this process are given below.

5.1.10.1 Detoxification of Metal Hydroxides and Chromates by Calcination

5.1.10.1.1 Process Description and Material Balance

This waste stream is usually dewatered and ready for calcination. Kaolin clay would be added to the waste sludge until a 20 percent by weight (dry basis) of solids is achieved. The mixture is conveyed to a rotary kiln where metal hydroxides and chromates are calcined at 900° C (1,650° F) and converted to oxides. Kaolin is added to immobilize heavy metals present in the calcined slag. The product from the kiln would be detoxified solid waste which could be disposed of in a sanitary landfill. The gaseous emissions from the kiln would contain carbon dioxide, carbon monoxide, particulates and water vapors which would be passed through a cyclone and electrostatic precipitator system for particulate control. Particulates would be recycled to the calciner.

Figure 31 shows a detailed flow sheet and an estimated material balance for a treatment plant to process waste sludges generated by a typical 182 kkg/day (200 tons/day) chromate plant.

5.1.10.1.2 Application to Date

a. Full-Scale Treatment Installation

None known.

TABLE 38

SYSTEM 13100, EQUIPMENT NEEDS, SPECIFICATIONS AND OPERATING CONDITIONS

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
13101	1	57,000 liters (15,000 gal) emulsified asphalt storage tank equipped with internal steam coils (holds 1 week's supply of asphalt - mild steel construction	Operates at 135° C (275° F) and 1 atm.
13102	1	7.6 l/min (2 gpm) emulsified asphalt transfer pump (gear pump) - stainless steel construction	Operates at 135° C (275° F) and total head of approximately 30.5 m (100 ft)
13103	1	28 cu m (1,000 cu ft) sludge hold tank - mild steel construction	Operates at 25° C (77° F) and 1 atm.
13104	1	19 l/min (5 gpm) sludge transfer pump (Moyno pump) - mild steel construction	Feeds 1.34 kkg/hr (1.48 tons/hr) of sludge from hold tank to wiped-film evaporator
13105	1	9.3 sq m (100 sq ft) wiped-film evaporator system - stainless steel construction	Processes a total of 1.35 kkg/hr (1.49 tons/hr) of emulsified asphalt and sludge feed at 150° C (302° F) and 1 atm. Discharged dry asphalted solids are suitable for landfilling
13106	1	14 cu m (500 cu ft) asphalted solids hold bin (holds 1 day's production) - mild steel construction	Operates at 40° C (104° F) and 1 atm. Asphalted solids are loaded daily into trucks and hauled to a landfill
13107	1	14 sq m (150 sq ft) condenser - mild steel construction on shell, copper tubes	Condenses approximately 80% of water vapor leaving wiped film evaporator (0.9 kkg/hr (0.99 tons/hr) of condensate). Condensate at about 40° C (104° F) drains to an accumulator
13108	1	760 liters (200 gal) accumulator - mild steel construction	Operates at 40° C (104° F) and 1 atm.

TABLE 38 (continued)

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
13109	1	28,000 l/min (1,000 CFM) exhaust fan - mild steel construction	Operates at 50° C (122° F) and 1 atm. Discharges non-condensables and water vapor to atmosphere
13110	1	19 l/min (5 gpm) centrifugal condensate recycle pump - cast iron construction	Operates at 40° C (104° F) and total head of approximately 30.5 m (100 ft.)

TABLE 39

TREATMENT SYSTEM 13100 - TOTAL INSTALLED CAPITAL COST

Equipment No. & Description	Installed Cost
13101 emulsified asphalt storage tank	$ 20,000
13102 emulsified asphalt transfer pump	800
13103 sludge hold tank	5,900
13104 sludge feed pump	1,900
13105 wiped-film evaporator system	167,000
13106 asphalted solids hold bin	5,000
13107 condenser	6,200
13108 accumulator	800
13109 offgas exhaust fan	1,200
13110 condensate recycle pump	1,300
Sub-total	$210,100
Piping and Valves @ 25%	52,500
Building, 92.9 sq m @ $387/sq m (1,000 sq ft @ $36/sq ft)	36,000
Sub-total	$298,600
Engineering @ 7%	20,900
Sub-total	$319,500
Contingency @ 20%	63,900
Total Installed Capital Cost	$383,400

TABLE 40

ANNUAL OPERATING COSTS FOR TREATMENT SYSTEM 13100

CAPITAL INVESTMENT	$383,400
VARIABLE COSTS	
Asphalt, 2,520,000 liters @ 10.6¢/l (666,000 gal @ 40¢/gal)	266,000
Direct operating labor, 2 men/shift @ $9/hr	112,300
Supervision and Administrative, @ 50% of direct operating labor	56,150
Maintenance @ 4% of capital investment	15,300
Power, 140,000 kwh @ 3¢/kwh	4,200
Process Heat (steam), 3.78×10^9 kg cal @ $15.87/MM kg cal (1.5 x 10^{10} BTU @ $4.00/MM BTU)	60,000
Sampling and Analysis	15,000
Waste Disposal, 4,080 kkg @ $6/kkg (4,496 tons @ $5.44/ton)	24,500
Total Variable Costs	$553,450
FIXED COSTS	
Capital Recovery Rate (10 yr. @ 10% equiv. to 0.1627/yr)	62,400
Taxes and Insurance @ 4% of capital investment	15,300
Total Fixed Costs	$77,700
TOTAL OPERATING COSTS	$631,150
Unit Costs	
$/kkg ($/ton) of sodium silicofluoride product	38 (34)
$/kkg ($/ton) of raw waste (dry basis)	247 (224)
$/kkg ($/ton) of raw waste (wet basis)	75 (68)

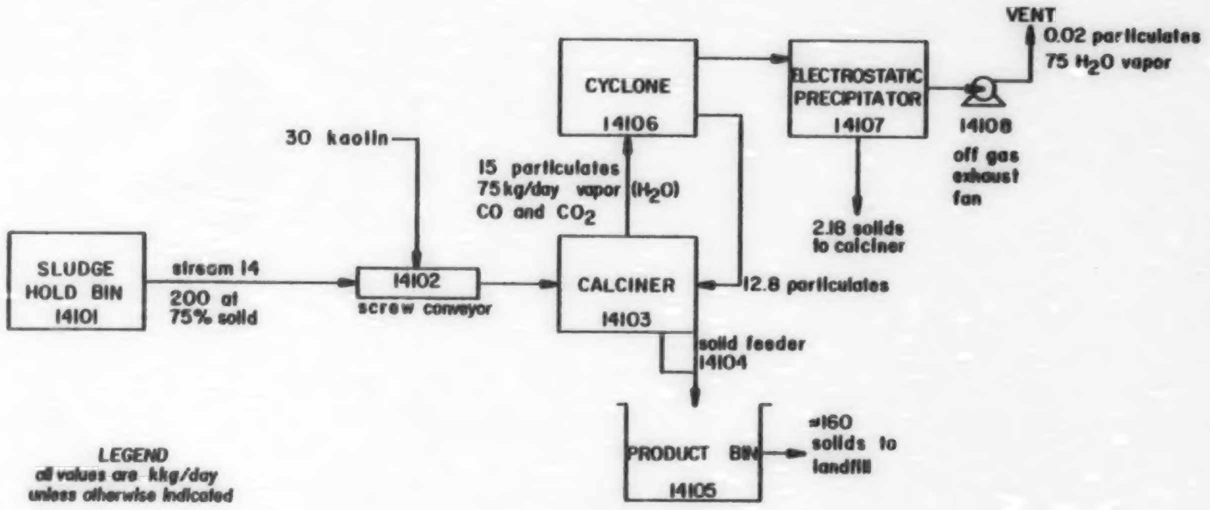

SLUDGE HOLD BIN 14101
stream 14
200 at 75% solid
30 kaolin
14102 screw conveyor
CALCINER 14103
15 particulates 75 kg/day vapor (H_2O) CO and CO_2
CYCLONE 14106
12.8 particulates
solid feeder 14104
PRODUCT BIN 14105
≈160 solids to landfill
ELECTROSTATIC PRECIPITATOR 14107
2.18 solids to calciner
14108 off gas exhaust fan
VENT
0.02 particulates
75 H_2O vapor
LEGEND
all values are kkg/day unless otherwise indicated

FIGURE 31 – DETOXIFICATION OF CHROMATE WASTES BY CALCINATION (system 14100)

b. Laboratory and Pilot Plant Operations

These are discussed under waste stream 8 (chrome color and inorganic pigment manufacturing), Section 5.1.6.1.2b.

c. Pilot or Full-Scale Operations Treating Similar Wastes

These are discussed in Section 5.1.6.1.2c.

5.1.10.1.3 Benefits and Environmental Consequences

a. Benefit Analysis Information

The benefits resulting from calcination of wastewater treatment sludges from chromate manufacturing operations are:

(1) solid waste detoxification and
(2) solid waste volume reduction.

The major benefit achieved by this system would be detoxification of hazardous components (hydroxides and chromates) in the waste stream through conversion to metal oxides which are insoluble in acid, alkali and water. This system would also achieve a volume reduction of land destine waste resulting in a cost savings of about $109,500 (excluding treatment process costs).

A summary of the benefits achieved by this process is shown in column 12 of Table 8.

b. Environmental Impact

There would be air emissions and solid waste generated by this treatment process. However, these wastes present no threat to the environment and personnel safety. This process is highly energy intensive.

Air Pollution

Air emissions from the calciner would be controlled by a cyclone and electrostatic precipitator in series. It is estimated that the controlled particulate emissions from this system would be a maximum of 20 kg/day which is within currently applicable limitations.

Water Pollution

None.

Solid Waste

There would be approximately 160 kkg/day of detoxified solid waste generated by this system.

Safety and Health Aspects

There are no personnel and safety hazards associated with this treatment process. The solid waste generated would be detoxified and should present no adverse environmental effects on disposal.

5.1.10.1.4 Costs for Detoxification of Chromium Bearing Wastewater Treatment Sludge and Ore Residue by Calcination

a. Process Design and Cost Evaluation Bases

The fundamental design considerations used in estimating costs for this process are:

(1) Chromium bearing sludge and ore residue as generated in a typical 182 kkg/day (200 tons/day) chromates plant would be processed in this treatment plant at the rate of 8.3 kkg/hr (9.1 tons/hr), 24 hours per day, 365 days per year. Chromium [as chromium (III) hydroxide and chromium (VI) chromate] is present to the extent of 1,500 ppm in the total sludge.

(2) The 200 kkg/day (220 tons/day) of sludge and ore residue would be mixed with 30 kkg/day (33 tons/day) of kaolin in a screw conveyor. The mixture would be then fed to a rotary calciner which operates at a maximum temperature of 900° C (1,652° F).

(3) The emissions from the calciner are treated in a cyclone and wet scrubber system with residual emissions in the vent being <2 kg/kkg (<4 lb/ton) of calcined residue.

b. Costing Methodology Used

The standard methodology discussed in Appendix II was used to develop costs for this treatment plant.

c. Cost Summary and Energy Requirements

The estimated total capital cost for system 14100 is $4,914,000. The estimated annual power and heat requirements are 980,000 kwh and 6.17×10^{10} kg cal (2.45×10^{11} BTU), respectively.

The estimated unit operating costs are as follows:

$59/kkg ($54/ton) of chromate chemicals
$72/kkg ($65/ton) of raw waste (dry basis)
$54/kkg ($49/ton) of raw waste (wet basis)

d. Detailed Process Equipment and Cost Information

Table 41 lists details on equipment size and operating conditions for this process. Breakdowns of total installed capital cost and annual operating costs are shown in Tables 42 and 43, respectively.

5.1.11 Waste Stream 15, Nickel-Containing Wastes From Wastewater Treatment - Nickel Sulfate Manufacture

A conceptualized resource recovery process has been selected for treating wastewater treatment sludges from nickel sulfate manufacturing plants. The process involves the recovery of nickel hydroxide by high gradient magnetic separation (HGMS). The waste stream under study is very small in volume and can be treated in a pilot size unit. There are off-the-shelf magnetic separators which could be used to treat this waste.

TABLE 41

SYSTEM 14100 - EQUIPMENT NEEDS, SPECIFICATIONS AND OPERATING CONDITIONS

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
14101	1	372 cu m (4,000 cu ft) sludge hold bin (holds 1 day's supply for plant) - mild steel construction	Operates at 25° C (77° F) and 1 atm.
14102	1	15.2 m (50 ft) sludge screw conveyor - mild steel construction	Conveys a total of 9.6 kkg/hr (10.6 tons/hr) of sludge and kaolin to calciner
14103	1	2.7 m x 91.4 m (9 ft x 300 ft) rotary calciner complete with product cooler, drive, burner, and controls - mild steel, refractory lined construction	Operates at a maximim temperature of 900° C (1,032° F) and 1 atm. Combustion gases flow counter-current to solids. Exit gases temperature is about 204° C (410° F). Calcined solids leave calciner cooling equipment at about 93° C (200° F). Heat utilization efficiency is about 40%.
14104	1	6.1 m (20 ft) calcined solids screw feeder - mild steel construction	Discharges 160 kkg/day (176 tons/day) of calcined solids to hold bin
14105	1	325 cu m (3,500 cu ft) calcined solids hold bin (holds 1 day's production) - mild steel construction	Operates at about 150° C (302° F) and 1 atm. Solids are loaded into trucks daily and hauled to a landfill
14106	1	198,000 l/min (7,000 CFM) cyclone - mild steel, refractory lined construction	Operates at 204° C (400° F) and 1 atm. Removes 12.8 kkg/day (14.1 tons/day) of particulates (operating efficiency of 85%) which are recycled to the rotary calciner
14107	1	198,000 l/min (7,000 CFM) electrostatic precipitator - mild steel construction	Operates at 204° C (400° F) and 1 atm. Removes 99% of particulates with 0.02 kkg/day (0.022 tons/day) being vented. Approximately 2.2 kkg/day (2.4 tons/day) of particulate is recycled to calciner

TABLE 41 (continued)

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
14108	1	198,000 l/min (7,000 CFM) exhaust fan - mild steel construction	Operates at 204° C (400° F) and 1 atm. Vents 0.02 kkg/day (0.022 tons/day) particulate and approximately 56 kkg/day (61.7 tons/day) of water vapor to atmosphere

TABLE 42

TREATMENT SYSTEM 14100 - TOTAL INSTALLED CAPITAL COST

Equipment No. & Description		Installed Cost*
14101	sludge hold bin	$ 16,000
14102	sludge conveyor	7,000
14103	rotary calciner system	2,915,000
14104	calcined solids screw feeder	2,000
14105	calcined solids hold bin	5,000
14106	cyclone	4,000
14107	electrostatic precipitator system	110,000
14108	offgas exhaust fan	3,000
	Sub-total	$3,062,000
Piping and Valves @ 25%		765,000
	Sub-total	$3,827,000
Engineering @ 7%		268,000
	Sub-total	$4,095,000
Contingency @ 20%		819,000
	Total Installed Capital Cost	$4,914,000

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* No additional building space would be required for this installation.

TABLE 43

ANNUAL OPERATING COSTS FOR TREATMENT SYSTEM 14100

CAPITAL INVESTMENT	$4,914,000
VARIABLE COSTS	
Kaolin, 10,900 kkg @ $160/kkg (12,011 tons @ $145/ton	1,716,000
Direct operating labor, 1 man/shift @ $9/hr	78,800
Supervision and Administrative @ 50% of direct operating labor	39,400
Maintenance @ 4% of capital investment	196,600
Power, 980,000 kwh @ 3¢/kwh	29,400
Process Heat, 6.17 x 10^{10} kg cal @ $15.87/MM kg cal (2.45 x 10^{11} BTU @ $2.00/MM BTU)	490,000
Sampling and Analysis	15,000
Waste Disposal, 58,400 kkg @ $6/kkg (64,357 tons @ $5.44/ton)	350,000
Total Variable Costs	$2,915,200
FIXED COSTS	
Capital Recovery Rate (10 yr. @ 10% equiv. to 0.1627/yr)	799,500
Taxes and Insurance @ 4% of capital investment	196,600
Total Fixed Costs	$ 996,100
TOTAL OPERATING COSTS	$3,911,300
Unit Costs	
$/kkg ($/ton) of chromate chemicals	59 (54)
$/kkg ($/ton) of raw waste (dry basis)	72 (65)
$/kkg ($/ton) of raw waste (wet basis)	54 (49)

5.1.11.1 Recovery of Nickel by HGMS

5.1.11.1.1 Process Description and Material Balance

The waste stream would be diluted with water to a concentration of 10 percent by volume of solids prior to treatment. Dilution is essential because the HGMS process is best suited for the removal of magnetic wastes that are present in low concentrations in a liquid stream.

HGMS uses fine ferromagnetic filament material containing 95 percent void space and magnets capable of generating high-intensity fields (up to 20,000 gauss) in large empty space. The nickel hydroxide would be collected in the filter by magnetic attraction as the waste stream passes through the unit. Nickel hydroxide trapped on the matrix during the feed cycle (magnet on) would be washed off the matrix and recovered during the flush cycle (magnet off). An automatic valving system would be used to collect the magnetic (nickel hydroxide) and nonmagnetic (detoxified sludge) products separately. The nickel hydroxide would be recovered as a 30 percent slurry and would be returned to the plant for reprocessing.

It is anticipated that the HGMS system would achieve a very high removal efficiency. Therefore, the purified stream would contain only traces of nickel hydroxide and may be pumped to the main plant treatment system or disposed of in a sanitary landfill.

Figure 32 shows a detailed flow sheet and an approximated material balance for a treatment plant to process waste sludge generated by a typical 9 kkg/day nickel sulfate plant. The treatment plant would recover 2.27 kg/day of 30 percent nickel hydroxide slurry and would generate 2.31 kkg/day detoxified sludge.

5.1.11.1.2 Applications to Date

a. Full-Scale Treatment Installations

None known.

b. Laboratory and Pilot Plant Operations

There are no known pilot plants or laboratory investigations experimenting with this waste stream. Laboratory tests to optimize processing conditions and a pilot plant to demonstrate the process would be required to validate this concept.

c. Pilot or Full-Scale Operations Treating Similar Wastes

The principal current commercial application of HGMS is the beneficiation of kaolin (clay) to remove a small unwanted magnetic fraction. Production prototypes were tested in 1969, and the first full-scale unit was put on-stream in early 1973. Today five kaolin producers in Georgia are each operating one HGMS unit. Four of these units were supplied by Aquafine Corporation (Brunswick, GA), and were constructed by Pacific Electric Motor Company. The fifth unit was supplied by Magnetic Corporation of America.[55]

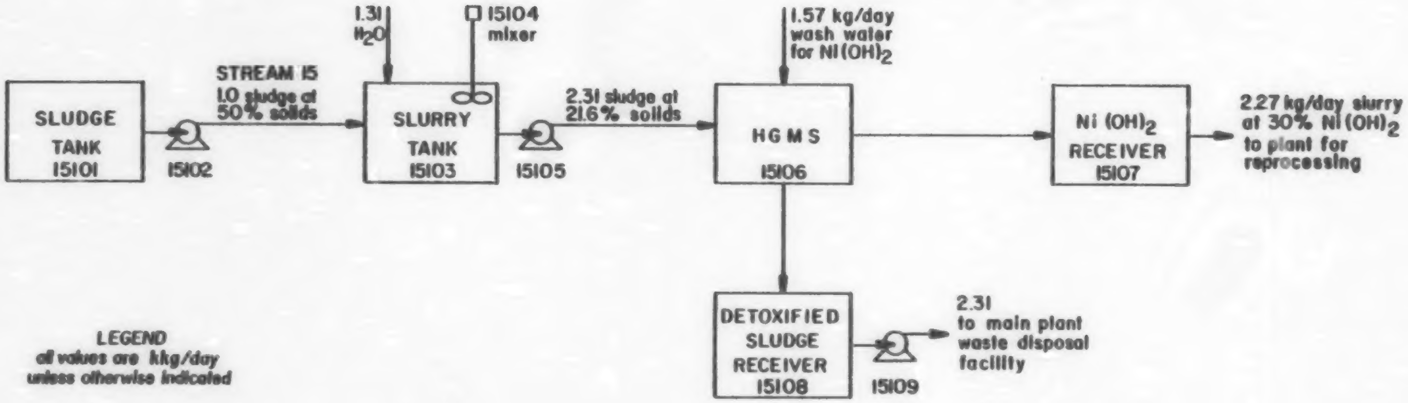
SLUDGE TANK 15101
15102
STREAM 15
1.0 sludge at 50% solids
1.31 H2O
15104 mixer
SLURRY TANK 15103
15105
2.31 sludge at 21.6% solids
1.57 kg/day wash water for Ni(OH)2
HGMS 15106
Ni(OH)2 RECEIVER 15107
2.27 kg/day slurry at 30% Ni(OH)2 to plant for reprocessing
DETOXIFIED SLUDGE RECEIVER 15108
15109
2.31 to main plant waste disposal facility
LEGEND
all values are kkg/day unless otherwise indicated

FIGURE 32 – RECOVERY OF NICKEL HYDROXIDE BY HIGH GRADIENT MAGNETIC SEPARATION (system 15100)

At least three HGMS research projects are under way in coal desulfurization. MIT's National Magnet Laboratory (NML) is currently looking at ash and sulfur removal from liquid coal in a project funded by the NSF and the Electric Power Research Institute. They expect to move to pilot plant trials in a year or two. Secondly, there is a pilot plant at Auburn University, Auburn, Alabama, where experiments are being done in conjunction with Aquafine Corporation. This work has resulted in the removal of over 90% of the pyritic sulfur in liquefied coal. Lastly, Aquafine Corporation is investigating the potential for removal of pyrites from dry pulverized coal under a prime contract held by Indiana University.[55]

The Massachusetts Metropolitan District Commission (MDS) has evaluated a solicited proposal for the use of an HGMS unit to help clean the Charles River.[65] The MDC was impressed by the capabilities of the proposed HGMS plant, but did not contract for the work. The costs seemed to outweigh the benefits at the time (late 1973).

No other water-treatment units are in use. Water purification applications are currently being explored by Sala Magnetics Corporation of Cambridge, Massachusetts, following initial work carried out in conjunction with MIT's National Magnet Laboratory.[65]

5.1.11.1.3 Benefits and Environmental Consequences

a. Benefit Analysis Information

The benefits resulting from the treatment of this waste stream by HGMS are:

(1) the recovery of nickel hydroxide and
(2) solid waste detoxification.

This system would achieve nickel hydroxide slurry recovery at a rate of 2.27 kg/day, which can be utilized at the plant site. Using an estimated price of $1.00 per kilogram of 30 percent nickel hydroxide slurry recovered, this treatment process would result in an annual cost savings of $590, or a cost savings of $0.01 per metric ton of nickel sulfate produced (excluding treatment process costs).

The resulting waste, although approximately doubled in volume as compared to the original waste, is detoxified and may be either sewered or sent to the plant's wastewater treatment system.

A summary of the benefits achieved by this process is shown in column 13 of Table 8.

b. Environmental Impact

There are no serious environmental impacts associated with the use of HGMS. The relatively large electrical energy requirements are of possible concern, but this too may be a minor issue considering the small volume of waste which would be treated by this system.

Air Pollution

None.

Water Pollution

None.

Solid Waste

There would be 2.31 kkg/day of detoxified sludge generated by this system.

Safety and Health Aspects

None.

5.1.11.1.4 Costs for Recovery of Nickel Hydroxide from Wastewater Treatment Sludges Using High Gradient Magnetic Separation

a. Process Design and Cost Evaluation Bases

The fundamental design considerations used in estimating costs for this process are:

(1) Sludge containing nickel hydroxide as generated in a typical 9 kkg/day (9.9 tons/day) nickel sulfate manufacturing plant would be processed in this treatment plant at the rate of 0.13 kkg/hr (0.14 tons/hr), 8 hours/day, 7 days/week.

(2) The sludge is diluted with water so that the solids loading is approximately 10% by volume. This slurry would be fed to the HGMS unit in a cyclic operation. The magnetic matrix of the HGMS would be loaded to capacity with solid nickel hydroxide, then flushed with fresh water to recover metal values. An HGMS unit with two matrices would be required, one collecting nickel hydroxide while the other was being flushed.

(3) The recovered nickel hydroxide (approximately 30% by weight slurry) would be recycled to the nickel sulfate manufacturing operation.

b. Costing Methodology Used

The standard methodology, discussed in Appendix II, was used to develop costs for this system except for the cost of the HGMS unit, which was supplied by a vendor.

c. Cost Summary and Energy Requirement

The estimated total capital cost for system 15100 is $99,200. The estimated annual power requirement is 320,000 kwh. The annual process heat requirement is negligible.

The unit operating costs are as follows:

$25/kkg ($23/ton) of nickel sulfate product
$424/kkg ($382/ton) of raw waste (dry basis)
$212/kkg ($192/ton) of raw waste (wet basis)

d. Detailed Process Equipment and Cost Information

Table 44 lists details on equipment size and operating conditions for this process. Breakdowns of total capital cost and annual operating costs are shown in Tables 45 and 46, respectively.

TABLE 44

SYSTEM 15100, EQUIPMENT NEEDS, SPECIFICATIONS AND OPERATING CONDITIONS

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
15101	1	760 liters (200 gal) sludge hold tank - mild steel construction	Operates at 25° C (77° F) and 1 atm.
15102	1	3.8 l/min (1 gpm) Moyno sludge pump - mild steel construction	Operates at 25° C (77° F) and total head of approximately 100 ft.
15103	1	2,300 liters(600 gal) slurry preparation tank, holds 1 day's supply of slurry feed to HGMS unit - mild steel construction	Operates at 25° C (77° F) and 1 atm.
15104	1	0.5 HP propeller mixer - stainless steel construction	Operates at 25° C (77° F)
15105	1	7.6 l/min (2 gpm) Moyno sludge pump - mild steel construction	Operates at 25° C (77° F) and total head of approximately 30.5 m (100 ft)
15106	1	10 cm (4 in) bore cyclic HGMS unit complete with automatic controls, twin separation units and internal heat exchanger for magnet cooling	Operates at 25° C (77° F) and 1 atm. Processes 2.31 kkg/day (2.54 tons/day) of a 10% by volume solids slurry. Recovers 0.7 kg (15.4 lb) of nickel hydroxide per day. Residual solids leaving HGMS unit are essentially nickel free
15107	1	19 liters (5 gal) nickel hydroxide slurry hold tank - mild steel construction	Operates at 25° C (77° F) and 1 atm. Unit collects 2.3 kg/day (5.06 lb/day) of a 30% by weight nickel hydroxide slurry. Receiver is emptied once a week with material recycled to nickel sulfate plant
15108	1	380 liters (100 gal) detoxified sludge hold tank - mild steel construction	Operates at 25° C (77° F) and 1 atm.
15109	1	7.6 liters (2 gpm) Moyno sludge pump - mild steel construction	Operates at 25° C (77° F) and a total head of approximately 30.5 m (100 ft). Pumps detoxified sludge from hold tank to main plant waste disposal facilities

TABLE 45

TREATMENT SYSTEM 15100 - TOTAL INSTALLED CAPITAL COST

Equipment No. & Description	Installed Cost
15101 sludge hold tank	$ 800
15102 sludge pump	600
15103 slurry preparation tank	1,200
15104 mixer	400
15105 sludge pump	900
15106 HGMS unit	48,000*
15107 detoxified sludge hold tank	300
15108 nickel hydroxide hold tank	70
15109 sludge pump	900
Sub-total	$53,170
Piping and Valves @ 25%	13,330
Building, 27.8 sq m @ $387/sq m (300 sq ft @ $36/sq ft)	10,800
Sub-total	$77,300
Engineering @ 7%	5,400
Sub-total	$82,700
Contingency @ 20%	16,500
Total Installed Capital Cost	$99,200

---

* Price was obtained from Mr. J. Iannielli, Sala Magnetics, Inc., Cambridge, Massachusetts

TABLE 46

ANNUAL OPERATING COSTS FOR TREATMENT SYSTEM 15100

CAPITAL INVESTMENT	$ 99,200
VARIABLE COSTS	
Direct operating labor, 1 man/shift @ $9/hr	26,300
Supervision and Administrative, @ 50% of direct operating labor	13,150
Maintenance, @ 4% of capital investment	4,000
Power, 320,000 kwh, @ 3¢/kwh	9,600
Sampling and Analysis	5,000
Total Variable Costs	$58,050
FIXED COSTS	
Capital Recovery Rate (10 yrs. @ 10% equiv. to 0.1627/yr)	16,100
Taxes and Insurance @ 4% of capital cost	4,000
Total Fixed Costs	$20,100
TOTAL OPERATING COST	$78,150
Credit for recovery of $Ni(OH)_2$, 850 kg @ $1.00/kg* (1,870 lb @ 45¢/lb)	(850)
NET OPERATING COST	$77,300
Unit Costs	
$/kkg ($/ton) of nickel sulfate product	25 (23)
$/kkg ($/ton) of raw waste (dry basis)	424 (382)
$/kkg ($/ton) of raw waste (wet basis)	212 (192)

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* Estimated value of 30% by weight slurry.

5.1.12 Waste Stream 16A, Calcium Fluoride Bearing Wastes from Phosphorus Manufacture

A conceptualized detoxification process consisting of evaporation and asphalting has been selected for treating calcium fluoride-containing wastewater treatment sludges from phosphorus manufacturing operations.

5.1.12.1 Detoxification of Calcium Fluoride Bearing Sludges by Evaporation and Asphalting

5.1.12.1.1 Process Description and Material Balance

This process has been described in detail in subsection 5.1.6.2.1 of this report.

Figure 33 shows a flow sheet and material balance for a treatment plant to process calcium fluoride bearing wastes generated by a typical 136 kkg/day phosphorus plant.

5.1.12.1.2 Application to Date

a. Full-Scale Treatment Installations

None known.

b. Laboratory and Pilot Plant Operation

This has been discussed in subsection 5.1.7.1.2b of this report.

c. Pilot Plant or Full-Scale Operation Treating Similar Wastes

This information has been discussed in detail in subsection 5.1.6.2.2c.

5.1.12.1.3 Benefits and Environmental Consequences

a. Benefit Analysis Information

The benefits resulting from this operation are:

(1) solid waste detoxification and
(2) the production of a clean water distillate that can be either safely discharged or reused.

The resulting solid waste would have approximately the same volume as the original waste sludge. However, the hazardous component would be intimately dispersed in the asphalt and immobilized for disposal.

A summary of the benefits achieved by this process is shown in column 14 of Table 8.

b. Environmental Impact

There are waterborne and solid wastes generated by this treatment process. However, these wastes present no threat to the environment and personnel safety. The major issues of concern are: (1) the system is

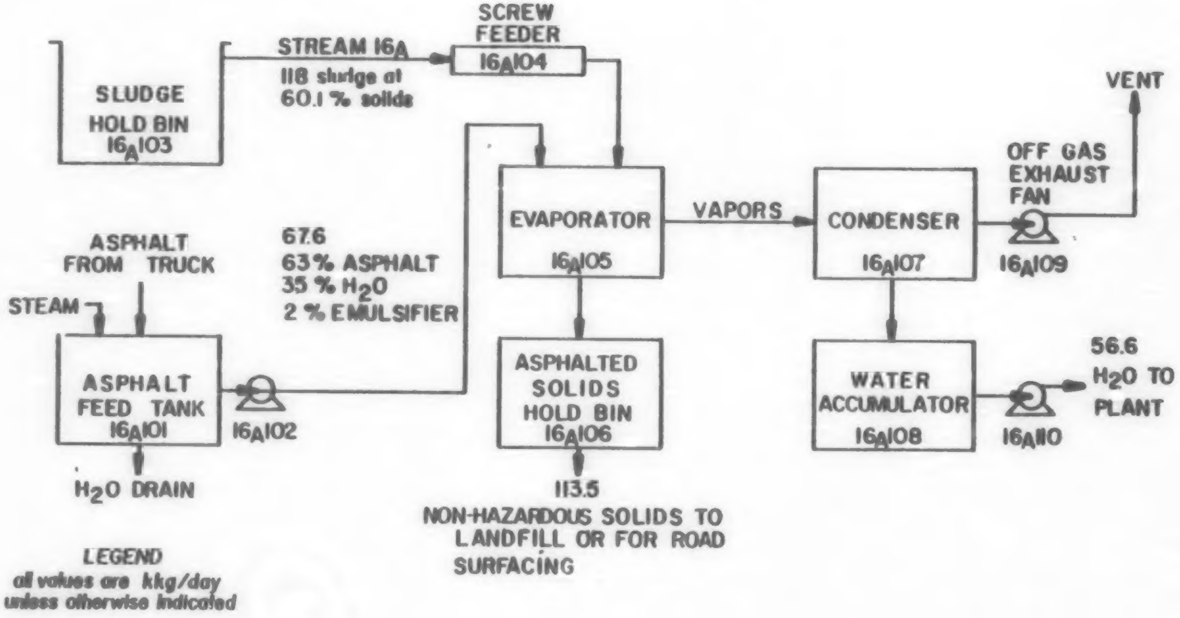
SLUDGE
HOLD BIN
16A103
STREAM 16A
118 sludge at
60.1 % solids
SCREW
FEEDER
16A104
ASPHALT
FROM TRUCK
STEAM
ASPHALT
FEED TANK
16A101
16A102
H2O DRAIN
67.6
63 % ASPHALT
35 % H2O
2 % EMULSIFIER
EVAPORATOR
16A105
ASPHALTED
SOLIDS
HOLD BIN
16A106
113.5
NON-HAZARDOUS SOLIDS TO
LANDFILL OR FOR ROAD
SURFACING
VAPORS
CONDENSER
16A107
WATER
ACCUMULATOR
16A108
OFF GAS
EXHAUST
FAN
16A109
VENT
16A110
56.6
H2O TO
PLANT
LEGEND
all values are kkg/day
unless otherwise indicated

FIGURE 33 - TREATMENT OF CALCIUM FLUORIDE BEARING WASTES BY EVAPORATION & ASPHALTING (system 16_A100)

highly energy intensive because of the need to evaporate large volumes of water, (2) the volume of asphalt required for this waste stream is large and its availability is highly variable throughout the nation. Also, asphalt may become scarce in the future because of the shortage of petroleum, and (3) there would be a constant need for new landfill areas if the product is proven to be unsuitable for use as aggregate.

Air Pollution

There are no air emission problems associated with this system. Water vapor from the evaporator would be condensed and collected.

Water Pollution

None.

Solid Waste

There would be approximately 114 kkg/day of non-hazardous solid waste generated by this system.

Safety and Health Aspects

None.

5.1.12.1.4 Costs for Detoxification of Calcium Fluoride Bearing Sludges by Evaporation and Asphalting

a. Process Design and Cost Evaluation Bases

The fundamental design considerations used in estimating costs for this process are:

(1) Calcium fluoride bearing wastewater treatment sludge, from a typical 136 kkg/day (150 tons/day) phosphorus plant, would be processed in the treatment plant at the rate of 4.9 kkg/hr (5.40 tons/hr), 24 hours/day, 260 days/year. Calcium fluoride is present up to 10% by weight (wet basis) in the sludge.

(2) The 118 kkg/day (130 tons/day) of sludge, containing approximately 60% solids, would be fed to a wiped-film evaporator together with 17.6 kkg/day (19.39 tons/day) of emulsified asphalt. In the evaporator, which operates at 150° C (302° F), approximately 71 kkg/day (78 tons/day) of water would be removed (essentially all of the water in the two feed streams). The evaporator would produce 114 kkg/day (126 tons/day) of dry asphalted solids which would be suitable for disposal in a sanitary landfill.

(3) Approximately 80% of the water removed in the wiped-film evaporator, would be condensed and recycled to the phosphorus plant for reuse. The offgases from the evaporator are assumed to be essentially particulate free.

b. Costing Methodology Used

The costing methodology used is the same as discussed in Section 5.1.6.2.4b.

c. Cost Summary and Energy Requirement

The estimated total capital cost for system 16A100 is $877,000. The estimated annual system power and heat (steam) requirements are 186,000 kwh and 1.76 x 10^{11} kg cal (7 x 10^{11} BTU), respectively.

The unit operating costs are as follows:

$56/kkg ($51/ton) of phosphorus product
$151/kkg ($137/ton) of raw waste (dry basis)
$91/kkg ($83/ton) of raw waste (wet basis)

d. Detailed Process Equipment and Cost Information

Table 47 lists details on equipment size and operating conditions for this process. Capital costs are presented in Table 48 and annual operating costs are presented in Table 49 for this plant.

5.1.13 Waste Stream 16B, Phossy Water - Phosphorus Manufacture

A conceptualized resource recovery process was selected to treat the phossy water waste stream generated during phosphorus manufacture. This process scheme combines existing and proven unit processes to achieve recovery of phosphorus as a product.

5.1.13.1 Recovery of Pure Phosphorus by Heat Treatment and Distillation

5.1.13.1.1 Process Description and Material Balance

In this process, phosphorus is recovered by heat treatment and distillation. The phossy water from the sludge feed tank, containing about 10 percent by weight solids, would be pumped into a clarifier. Flocculant is added to this sludge to agglomerate small suspended particles. The overflow from this clarifier would be recycled to the main plant for reuse. The underflow, containing about 25 percent by weight solids, would be pumped into a steam jacketed tank. The applied heat melts the phosphorus and facilitates its settling and separation. The recovered phosphorus is recycled to the main plant and processed through a filter press, while the overflow from the heating tank is pumped into a rotary still where residual phosphorus is recovered by distillation at 360° C (700°F). The vapors from the still, containing phosphorus and water, would be condensed and collected in an accumulator. The phosphorus from the accumulator would be recycled to the main plant and processed through a filter press. The water from the condenser accumulator, which may contain some phosphorus, would be recycled to the clarifier. The residue from the still would be returned to the original phossy water pond.

Figure 34 shows a detailed flow sheet and material balance for a treatment plant to process the phossy water generated by a typical 136 kkg/day (150 tons/day) phosphorus plant.

TABLE 47

SYSTEM 16A100, EQUIPMENT NEEDS, SPECIFICATIONS AND OPERATING CONDITIONS

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
16A101	1	380,000 liters (100,000 gal) emulsified asphalt storage tank equipped with internal steam coils (holds 1 week's supply of emulsified asphalt) - mild steel construction	Operates at 135° C (275° F) and 1 atm.
16A102	1	57 l/min (15 gpm) emulsified asphalt transfer pump (gear pump) - cast iron construction	Operates at 135° C (275° F) and total head of approximately 30.5 m (100 ft)
16A103	1	76,000 liters (20,000 gal) sludge hold tank (holds 1 day's feed to wiped-film evaporator) - mild steel construction	Operates at 25° C (77° F) and 1 atm.
16A104	1	15 m (50 ft) sludge screw feeder - mild steel construction	Delivers 4.9 kkg/hr (5.4 tons/hr) of sludge to wiped-film evaporator
16A105	1	21 sq m (230 sq ft) wiped-film evaporator system - stainless steel clad mild steel construction	Processes a total of 7.7 kkg/hr (8.5 tons/hr) of emulsified asphalt and sludge feed at 150° C (302° F) and 1 atm. Discharged dry asphalted solids are suitable for landfilling
16A106	1	84 cu m (3,000 cu ft) asphalted solids hold bin (holds 1 day's production) - mild steel construction	Operates at 40° C (104° F) and 1 atm. Asphalted solids are loaded daily into trucks and hauled to a landfill
16A107	1	28 sq m (300 sq ft) condenser - mild steel construction on shell, copper tubes	Condenses approximately 80% of water vapor leaving wiped-film evaporator (2.4 kkg/hr (2.6 tons/hr) of condensate). Condensate at about 40° C (104° F) drains to an accumulator
16A108	1	1,900 liters (500 gal) accumulator - mild steel construction	Operates at 40° C (104° F) and 1 atm.

TABLE 47 (continued)

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
16A109	1	43,000 l/min (1,500 CFM) exhaust fan - mild steel construction	Operates at 50° C (122° F) and 1 atm. Discharges noncondensables and water vapor to atmosphere
16A110	1	38 l/min (10 gpm) centrifugal condensate recycle pump - cast iron construction	Operates at 40° C (104° F) and total head of approximately 30.5 m (100 ft)

TABLE 48

TREATMENT SYSTEM 16A100 - TOTAL INSTALLED CAPITAL COST

Equipment No. & Description		Installed Cost
16A101	emulsified asphalt storage tank	$ 90,000
16A102	emulsified asphalt transfer pump	1,500
16A103	sludge hold tank	9,500
16A104	sludge screw feeder	4,800
16A105	wiped-film evaporator system	350,000
16A106	asphalted solids hold bin	10,800
16A107	condenser	18,300
16A108	accumulator	1,400
16A109	offgas exhaust fan	1,200
16A110	condensate recycle pump	1,000
	Sub-total	$488,500
Piping and Valves @ 25%		122,100
Building, 186 sq m @ $387/sq m (2,000 sq ft @ $36/sq ft)		72,000
	Sub-total	682,600
Engineering @ 7%		47,800
	Sub-total	730,400
Contingency @ 20%		146,100
	Total Installed Capital Cost	$876,500

TABLE 49

ANNUAL OPERATING COSTS FOR TREATMENT SYSTEM 16A100

CAPITAL INVESTMENT	$ 876,500
VARIABLE COSTS	
Asphalt 18.32 MM liters @ 10.6¢/1 (4.84 MM gal @ 40¢/gal)	1,940,000
Direct operating labor, 2 men/shift @ $9/hr	112,300
Supervision and Administrative, @ 50% of direct operating labor	56,150
Maintenance, @ 4% of capital investment	35,000
Power, 186,000 kwh @ 3¢/kwh	5,600
Process Heat (steam), 1.76 x 10^{11} kg cal @ $15.87/MM kg cal (7 x 10^{11} BTU @ $4.00/MM BTU)	280,000
Sampling and Analysis	10,000
Waste Disposal, 29,500 kkg @ $6/kkg (32,500 tons @ $5.44/ton)	177,000
Total Variable Costs	$2,616,050
FIXED COSTS	
Capital Recovery Rate (10 yrs. @ 10%equiv. to 0.1627/yr)	142,600
Taxes and Insurance, @ 4% of capital cost	35,000
Total Fixed Costs	$177,600
TOTAL OPERATING COST	$2,793,650
Unit Costs	
$/kkg ($/ton) of phosphorus product	56 (51)
$/kkg ($/ton) of raw waste (dry basis)	151 (137)
$/kkg ($/ton) of raw waste (wet basis)	91 (83)

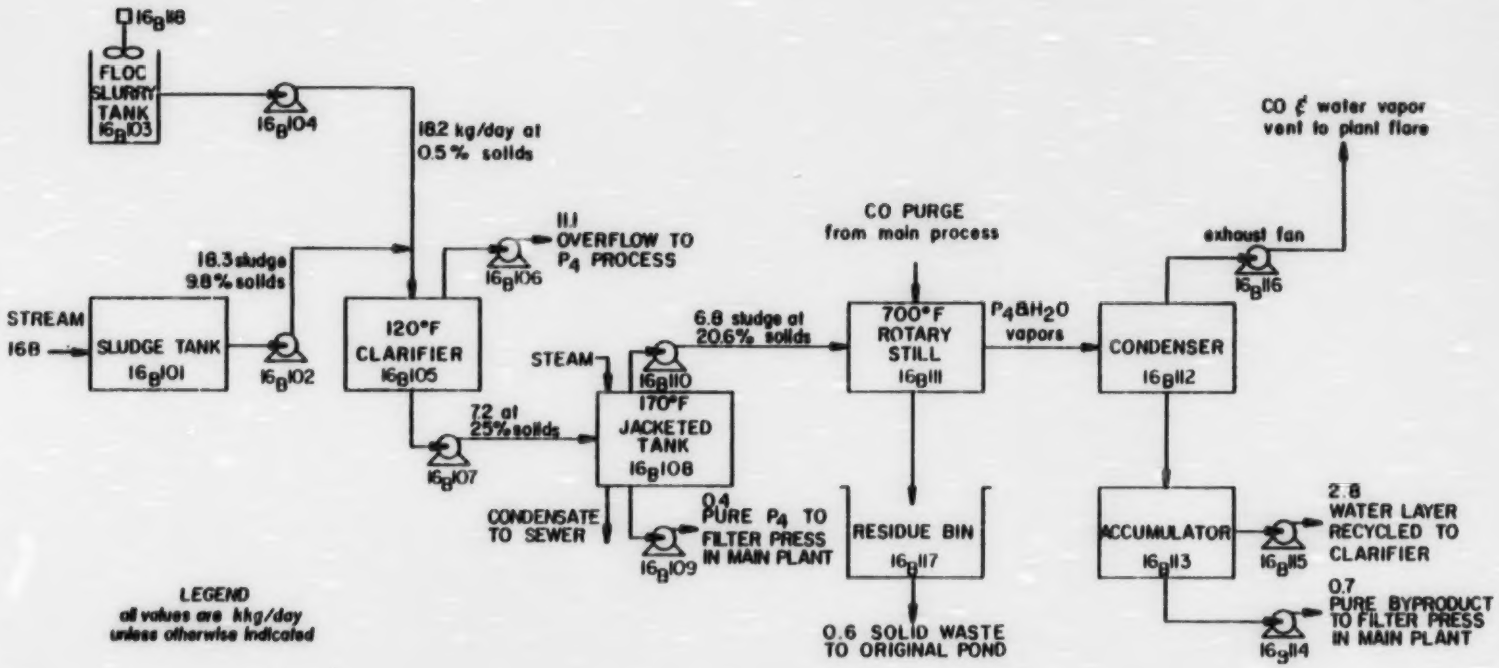
16B118
FLOC SLURRY TANK 16B103
16B104
18.2 kg/day at 0.5 % solids
16.3 sludge 9.8 % solids
STREAM 16B
SLUDGE TANK 16B101
16B102
120°F CLARIFIER 16B105
11.1 OVERFLOW TO P_4 PROCESS
16B106
7.2 at 25% solids
16B107
STEAM
16B110
170°F JACKETED TANK 16B108
CONDENSATE TO SEWER
0.4 PURE P_4 TO FILTER PRESS IN MAIN PLANT
16B109
6.8 sludge at 20.6% solids
CO PURGE from main process
700°F ROTARY STILL 16B111
RESIDUE BIN 16B117
0.6 SOLID WASTE TO ORIGINAL POND
P_4 & H_2O vapors
CONDENSER 16B112
exhaust fan
16B116
CO & water vapor vent to plant flare
ACCUMULATOR 16B113
16B115
2.8 WATER LAYER RECYCLED TO CLARIFIER
16B114
0.7 PURE BYPRODUCT TO FILTER PRESS IN MAIN PLANT
LEGEND
all values are kkg/day unless otherwise indicated

FIGURE 34 - RECOVERY OF PHOSPHORUS BY HEAT TREATMENT & DISTILLATION (system 16_B100)

5.1.13.1.2 Application to Date

a. Full-Scale Treatment Installation

There are no known full-scale installations using this process in its entirety. However, two companies have operated on a full scale the two main unit processes of this system, which are the steam jacketed separation tank and the rotary still. Electro-phos in Pierce, Florida, has operated the steam jacketed separator intermittently to recover phosphorus from the phossy water waste stream generated by a 59 kkg/day (65 tons/day) phosphorus plant. This plant has successfully recovered 1/3 of the phosphorus in this waste stream when utilizing this technique. Stauffer Chemical in Mt. Pleasant, Tennessee, has successfully operated a rotary still intermittently to recover the phosphorus in various sludges generated by a 113 kkg/day (125 tons/day) phosphorus plant. Although individual unit processes have been demonstrated successfully, a pilot plant run to demonstrate the completely integrated treatment process would be necessary.

b. Laboratory and Pilot Plant Operations

None known.

c. Pilot or Full-Scale Operations Treating Similar Wastes

None known.

5.1.13.1.3 Benefits and Environmental Consequences

a. Benefit Analysis Information

The benefits resulting from the treatment of phossy water are:

(1) the recovery of phosphorus and
(2) waste volume reduction.

This system would recover phosphorus at a rate of 1.1 kkg/day. Using a price of $0.80 per kilogram of recovered material, this treatment process would result in a resource recovery value of $321,000 or $6.50 per metric ton of phosphorus manufactured.

The treatment plant will also achieve an annual cost savings of $13,000 (assumes $2 per metric ton phossy pond cost) resulting from the reduction of volume of land destined waste (excluding treatment process costs).

A summary of the benefits achieved by this process is shown in column 15 of Table 8.

b. Environmental Impact

There would be solid waste generated by this process which may contain residual phosphorus. However, the major concern is that this process is highly energy intensive.

Air Pollution

The vapors from the still would be totally condensed and present no air emission problem.

Water Pollution

There would be no water borne waste generated by this process. The overflow from the clarifier would be recycled to the main plant for reuse. The water from the accumulator may contain residual phosphorus and would be recycled to the clarifier for reprocessing

Solid Waste

There would be approximately 0.6 kkg/day of solid waste generated which could contain traces of phosphorus. This material could be sent to the original phossy pond.

Safety and Health Aspects

Colloidal phosphorus is hazardous. Even though the concentration of phosphorus in the waste stream would be low, it would require safeguards upon land disposal.

Phosphorus poisoning is a potential occupational hazard at elemental phosphorus production plants. The OSHA limit for yellow phosphorus is 0.1 mg/cubic meter of air over an 8 hour time weighted average. Details on the occupational and health effects of phosphorus are given in Appendix I.

5.1.13.1.4 Costs for Phosphorus Recovery from Phossy Water

a. Process Design and Cost Evaluation Bases

The fundamental design considerations used in estimating costs for this process are:

(1) Phossy water generated by a typical 135 kkg/day (149 tons/day) elemental phosphorus plant would be fed to the phosphorus recovery process at the rate of 0.79 kkg/hr (0.87 tons/hr), 24 hours per day, 365 days per year. The phossy water contains approximately 10% by weight of phosphorus.

(2) By the use of flocculant and a clarifier-thickener, the solids loading of the phosphorus bearing stream would be increased to 25% by weight in the thickener underflow.

(3) The thickener underflow would be fed to a steam jacketed tank maintained at a temperature of 71° C (170°F). At this temperature phosphorus becomes molten and would stratify into a bottom layer of pure phosphorus which would be recycled to the main plant. Approximately 1/3 of the phosphorus in the sludge is recoverable in this manner. The upper layer in the tank would consist of water, molten phosphorus and various impurities.

(4) Distillation of the phosphorus-water mixture from step (3) in a continuous rotary still would yield 1.1 kkg/day (1.2 tons/day) of pure phosphorus as product.

b. Costing Methodology Used

The standard methodology, discussed in Appendix II was used to develop costs for this treatment plant.

c. Cost Summary and Energy Requirement

The estimated total capital cost for system 16B100 is $544,000. The estimated annual system power and heat requirements are 196,000 kwh and 1.84×10^9 kg cal (7.3×10^9 BTU), respectively.

The unit operating costs are as follows:

$1.6/kkg ($1.5/ton) of phosphorus product
$120/kkg ($109/ton) of raw waste (dry basis)
$12/kkg ($11/ton) of raw waste (wet basis)

d. Detailed Process Equipment and Cost Information

Table 50 lists details on equipment size and operating conditions for this process. Total capital cost is presented in Table 51 and an annual operating cost breakdown is presented in Table 52.

5.1.14 Waste Stream 18, Arsenic Chloride Wastes from Phosphorus Trichloride Manufacture

A conceptual process design has been prepared for a treatment plant to recover impure arsenic trichloride by distillation. Details on this process are given below.

5.1.14.1 Recovery of Impure Arsenic Trichloride by Distillation

5.1.14.1.1 Process Description and Material Balance

A batch still would be charged with the waste and the charge would be heated to 150° C. Vapors of arsenic trichloride would be condensed in a chilled water condenser and set to an accumulator. This impure arsenic trichloride would be drummed and sent to a secondary arsenic trichloride refining facility. One such facility is the Great Western Inorganics in Golden,Colorado, who presently accepts impure arsenic chloride streams for refining to pure product.

The still bottoms from this operation would be landfilled. The off-gases consisting of non-condensables would be vented.

Figure 35 shows a detailed flow sheet and material balance for a treatment plant to process wastes generated by a typical 159 kkg/day (175 tons/day) phosphorus trichloride plant.

TABLE 50

SYSTEM 16B100, EQUIPMENT NEEDS, SPECIFICATIONS AND OPERATING CONDITIONS

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
16B101	1	19,000 liters (5,000 gal) sludge hold tank (1 day's sludge production) - rubber-lined mild steel construction	Operates at 25° (77° F) and 1 atm.
16B102	1	15 l/min (4 gpm) sludge transfer pump - stainless steel construction	Operates at 25° C (77° F) and total head of approximately 100 ft.
16B103	1	190 liters (50 gal) flocculant preparation tank - mild steel construction	Operates at 25° C (77° F) and 1 atm.
16B104	1	1.5 ml/min (4.0×10^{-5} gal/min) floc slurry metering pump - stainless steel construction	Operates at 25° C (77° F) and 137.1 atm (2,000 psi) maximum pumping head
16B105	1	2.74 m (9 ft) diameter clarifier-thickener - rubber-lined mild steel construction	Processes 21.1 kkg/day (23 tons/day of approximately 8% solids feed slurry (with floc addition) to yield an underflow of 7.2 kkg/day (7.9 tons/day) solids and an overflow of 16.6 kkg/day (18.3 tons/day), the latter recycled to the main plant
16B106	1	11 l/min (3 gpm) centrifugal thickener overflow liquor transfer pump - stainless steel construction	Operates at 25° C (77° F) and total head of approximately 30.5 m (100 ft). Would return this stream to main plant process water use
16B107	1	760 l/min (2 gpm) Moyno slurry transfer pump - stainless steel construction	Operates at 25° C (77° F) and total head of approximately 30.5 m (100 ft)

TABLE 50 (continued)

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
16B108	1	0.9 m diameter x 2.7 m tall (3 ft x 9 ft) steam jacketed heat treatment tank - stainless steel construction	Operates at 77° C (170° F) and 1 atm. With approximately 4 hr. residence time in the tank, the phosphorus in the feed solids would melt and about 1/3 of this material would separate to the bottom of the tank as a layer of relatively pure P_4. The upper layer would consist of a mixture of water, P_4 and impurities. The pure P_4 bottom layer would be pumped to the main plant processing facilities at a rate of 0.4 kkg/day (0.44 tons/day). This would be done intermittently (once an hour)
16B109	1	3.8 l/min (1 gpm) Moyno P_4 transfer pump - stainless steel construction	Operates at 77° C (177° F) and total head of approximately 30.5 m (100 ft)
16B110	1	7.6 l/min (2 gpm) Moyno slurry transfer pump - stainless steel construction	Operates at 77° C (170° F) and total head of approximately 30.5 m (100 ft)
16B111	1	0.9 m diameter x 12 m long (3 ft x 40 ft) inclined rotary still, externally fired - stainless steel construction	Operates at a maximum temperature of 371° C (700° F) and 1 atm. Still would process 6.8 kkg/day (7.5 tons/day) of slurry (approximately 21% solids). Initially, the water would be vaporized and at a temperature > 260° C (>500° F), the P_4 in the feed would be vaporized. Approximately 0.6 kkg/day of residue would discharge from the bottom end of the still. The vapor would be drawn out of the still using a continuous carbon monoxide purge (phosphorus furnace offgas) to avoid any oxygen presence in the P_4 vapor and thereby avoid combustion of the P_4.

TABLE 50 (continued)

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
16B112	1	9.29 sq m (100 sq ft) vertical condenser - stainless steel construction	Unit would condense all of the P_4 vapor [0.7 kkg/day (0.77 tons/day)] and approximately 50% of the water vapor. The condensed P_4 and water leave the unit at about 49° C (120° F) and drain to an accumulator
16B113	1	950 liters (250 gal) accumulator - stainless steel construction	Operates at 49° C (100° F) and 1 atm. Would discharge 0.7 kkg/day (0.77 tons/day) of molten phosphorus to main plant processing facilities on an intermittent basis, and 2.8 kkg/day (3.1 tons/day) of P_4-bearing water layer to clarifier 16105
16B114	1	7.6 l/min (2 gpm) Moyno molten phosphorus transfer pump - stainless steel construction	Operates at 49° C (120° F) and total head of approximately 30.5 m (100 ft)
16B115	1	3.8 l/min (1 gpm) centrifugal transfer pump - stainless steel construction	Operates at 49° C (120° F) and total head of approximately 30.5 m (100 ft)
16B116	1	2,800 l/min (100 CFM) exhaust fan - stainless steel construction	Operates at 49° C (120° F) and 1 atm. Discharges a mixture of carbon monoxide and water vapor to main plant carbon monoxide flare
16B117	1	4.2 cu m (150 cu ft) residue hold bin (holds 1 week's production of solid residue from rotary still 16B111) - mild steel construction	Operates at average temperature of 66° C (150° F) and 1 atm. Residue would be essentially phosphorus-free. This material would be discharged once a week to available phossy water ponds on site.
16B118	1	0.25 HP propeller agitator - mild steel construction	Operates at 25° C (77° F)

TABLE 51

TREATMENT SYSTEM 16B100 - TOTAL INSTALLED CAPITAL COST

Equipment No. & Description	Installed Cost
16B101 sludge hold tank	$ 9,000
16B102 sludge pump	1,000
16B103 floc slurry tank	400
16B104 floc metering pump	600
16B105 clarifier-thickener	38,000
16B106 clarifier-thickener overflow pump	800
16B107 clarifier-thickener underflow pump	1,400
16B108 steam jacketed tank	2,000
16B109 molten phosphorus pump	1,000
16B110 phosphorus slurry pump	1,400
16B111 rotary still	200,000
16B112 condenser	20,000
16B113 accumulator	1,400
16B114 molten phosphorus pump	1,400
16B115 water pump	800
16B116 exhaust fan	600
16B117 residue bin	2,000
16B118 agitator	200
Sub-total	$282,000
Piping and Valves @ 25%	70,000
Building, 186 sq m @ $387/sq m (2,000 sq ft @ $36/sq ft)	72,000
Sub-total	$424,000
Engineering @ 7%	29,700
Sub-total	$453,700
Contingency @ 20%	90,700
Total Installed Capital Cost	$544,400

TABLE 52

ANNUAL OPERATING COSTS FOR TREATMENT SYSTEM 16B100

CAPITAL INVESTMENT	$544,400
VARIABLE COSTS	
Treatment Chemicals (flocculant)*	2,000
Direct operating labor, 2 men/shift @ $9/hr.	157,800
Supervision and Administrative, @ 50% of direct labor	78,900
Maintenance @ 4% of capital investment	21,800
Power, 196,000 kwh @ 3¢/kwh	5,900
Process Heat, 1.84 x 10^9 kg cal @ $7.94/MM kg cal (7.3 x 10^9 BTU @ $2.00/MM BTU)	14,600
Sampling and Analysis	10,000
Total Variable Costs	$291,000
FIXED COSTS	
Capital Recovery Rate (10 yrs. @ 10% equiv. to 0.1627/yr)	88,600
Taxes and Insurance @ 4% Capital Cost	21,800
Total Fixed Costs	$110,400
TOTAL OPERATING COST	$401,400
Less Credit for Recovered Phosphorus, 401 kkg @ $800/kkg ** (442 tons @ $725.6/ton)	(321,000)
NET ANNUAL OPERATING COST	$80,400
Unit Costs	
$/kkg ($/ton) of phosphorus product	$1.6 (1.5)
$/kkg ($/ton) of raw waste (dry basis)	$120 (109)
$/kkg ($/ton) of raw waste (wet basis)	$12 (11)

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* Versar estimate

** Selling price of yellow P_4 is $1,340/kkg.[17] The recovered material is assumed to be worth 60% of this value.

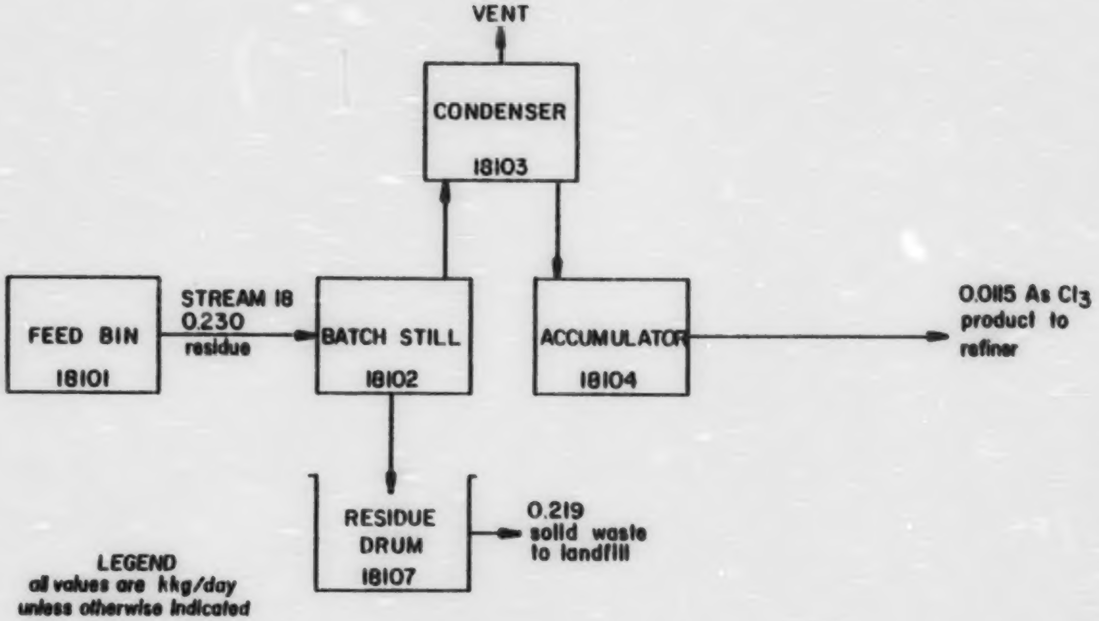
VENT
CONDENSER
18103
FEED BIN
18101
STREAM 18
0.230
residue
BATCH STILL
18102
ACCUMULATOR
18104
0.0115 As Cl_3
product to
refiner
RESIDUE
DRUM
18107
0.219
solid waste
to landfill
LEGEND
all values are kkg/day
unless otherwise indicated

FIGURE 35 - RECOVERY OF ARSENIC TRICHLORIDE BY DISTILLATION (system 18100)

5.1.14.1.2 Application to Date

a. Full-Scale Treatment Installation

None known.

b. Laboratory and Pilot Plant Operations

There are no known pilot plants or laboratory investigations experimenting with this waste stream. Laboratory tests to optimize processing conditions and a pilot plant to demonstrate the process would be required.

c. Pilot or Full-Scale Operations Treating Similar Wastes

Great Western Inorganics Company in Golden, Colorado, uses distillation techniques to recover pure arsenic trichloride from impure feedstocks. The key contact at this plant is Mr. J. Bernon, President.

5.1.14.1.3 Benefits and Environmental Consequences

a. Benefit Analysis Information

The benefits resulting from this treatment system are:

(1) waste detoxification and
(2) recovery of impure arsenic trichloride.

This system would recover arsenic trichloride at a rate of 11.5 kg/day. The annual cost savings resulting from this treatment process are negligible. The virtue of the process is the detoxification of the waste and the production of an intermediate material which has a market and could be reprocessed to a pure product.

The summary of the benefits achieved by this process is shown in column 16 of Table 8.

b. Environmental Impact

There would be air emissions and solid waste generated by this process. However, these wastes present no threat to the environment and personnel safety. The relatively large energy requirements are a possible concern, but this too may be a minor issue considering the small volume of waste generated and treated.

Air Pollution

The vapors from the still would be condensed in a chilled water condenser and the non-condensables would be vented. It is anticipated that there would be no serious air emissions problems associated with this process.

Water Pollution

None.

Solid Waste

There would be approximately 220 kilograms per day of solid detoxified waste generated by this process.

Safety and Health Aspects

It is anticipated that there would be no safety and health hazards associated with this process. OSHA's proposed new guidelines for workplace exposure to inorganic arsenic is a maximum of 0.004 mg/m^3 and an "action level" of 0.002 mg/m^3. Details of occupational and health effects of arsenic and arsenic chloride are given in Appendix I.

5.1.14.1.4 Costs for Recovery of Impure Arsenic Trichloride by Distillation of Phosphorus Trichloride Still Bottoms

a. Process Design and Cost Evaluation Bases

The fundamental design considerations used in estimating costs for this process are:

(1) Arsenic trichloride bearing still bottoms generated from a typical 58,000 kkg/yr (63,900 tons/yr) phosphorus trichloride manufacturing operation would be fed batch wise to this process, one batch per day (165 kg/day, 363 lb/day), 260 days per year.

(2) The waste would be processed in a batch still - one batch per 8 hour day at a maximum distillation temperature of 105° C and 1 atm. pressure. The distillation operation would recover 11.5 kg/day (25.3 lb/day) of $AsCl_3$ (essentially all of the $AsCl_3$ in the feed), with the residue consisting of ferric chloride and glassy phosphate material. The detoxified residue could be drummed and landfilled.

(3) The impure $AsCl_3$ recovered in the distillation operation would be sent to a processor of this chemical.*

b. Costing Methodology Used

The standard methodology, discussed in Appendix II, was used to develop costs for this treatment plant.

c. Cost Summary and Energy Requirement

The estimated total capital cost for system 18100 is $46,000. The estimated annual system power and heat requirements are quite small and are considered negligible in the estimate.**

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*Great Western Inorganics, Golden, Colorado, has indicated a desire to acquire this material and would supply special shipping containers to hold and transport the arsenic trichloride.

**The annual heat requirement is approximately 2.52×10^5 kg cal (1×10^6 BTU). The annual power requirement is on the order of 1,000 kwh.

The unit operating costs are as follows:

$1.8/kkg ($1.6/ton) of phosphorus trichloride product
$1,740/kkg ($1,580/ton) of raw waste, dry basis (there is no water in this waste stream).

d. Detailed Process Equipment and Cost Information

Table 53 lists details on equipment size and operating conditions for this process. Total capital cost is presented in Table 54 and an annual operating cost breakdown is presented in Table 55.

TABLE 53

SYSTEM 18100, EQUIPMENT NEEDS, SPECIFICATIONS AND OPERATING CONDITIONS

Equipment No.	Quantity	Equipment Specifications	Operating Conditions
18101	1	0.56 cu m (25 cu ft) still bottoms hold bin (holds 1 week's supply of feed to batch still) - mild steel construction	Operates at 25° C (77° F) and 1 atm.
18102	1	190 liters (50 gal) steam jacketed batch still - mild steel construction	Operates at a maximum temperature of 150° C (302° F) and 1 atm. Unit would be hand-loaded once a day from hold bin. Unit would vaporize 11.5 kg/day (25.3 lb/day) of $AsCl_3$ over an 8-hour batch cycle
18103	1	0.9 sq m (10 sq ft) refrigerated condenser - stainless steel construction	Operates at a condensate outlet temperature of approximately 10° C (50° F) and 1 atm (conditions at which the vapor pressure of $AsCl_3$ is negligible). Vent from the condenser contains only non-condensables. $AsCl_3$ condensate drains into accumulator
18104	1	19 liters (5 gal) accumulator (holds 1 week's production of $AsCl_3$) - stainless steel construction	Operates at 25° C (77° F) and 1 atm. Contents of accumulator are discharged once a week into special shipping container supplied by Great Western Inorganics
18105	5/week	208 liters(55 gal) drums - each holds approximately one day's production of still bottoms from batch still 18100 - plastic lined steel drums	Approximately 5 drums per week of detoxified still bottoms are hauled to a sanitary landfill

TABLE 54

TREATMENT SYSTEM 18100 - TOTAL INSTALLED CAPITAL COST

Equipment No. & Description	Installed Cost*
18101 still bottoms hold bin	$ 200
18102 batch still	25,000
18103 refrigerated condenser	3,000
18104 accumulator	100
18105 plastic lined steel drums	**
Sub-total	$28,300
Piping and Valves @ 25%	7,100
Sub-total	$35,400
Engineering @ 7%	2,500
Sub-total	$37,900
Contingency @ 20%	7,600
Total Installed Capital Cost	$45,500

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* No additional building space would be needed for this process.

** Cost of drums included in operating costs.

TABLE 55

ANNUAL OPERATING COSTS FOR TREATMENT SYSTEM 18100

CAPITAL INVESTMENT	$ 45,500	
VARIABLE COSTS		
Direct operating labor, 1 man/shift @ $9/hr.	56,200	
Supervision and Administrative, @ 50% of direct operating labor	28,100	
Maintenance @ 4% of capital cost	1,800	
Drums, 260 @ $15/drum	3,900	
Sampling and Analysis	5,000	
Waste Disposal, 57 kkg @ $6/kkg (62.8 tons @ $5.44/ton)	340	
Total Variable Costs	$95,340	
FIXED COSTS		
Capital Recovery Rate (10 yrs. @ 10% equiv. to 0.1627/yr	7,400	
Taxes and Insurance, @ 4% of capital cost	1,800	
Total Fixed Costs	$9,200	
TOTAL OPERATING COST		
Credit for recovery of Arsenic Trichloride	0*	
NET OPERATING COST	$104,540	
Unit Costs		
$/kkg ($/ton) of phosphorus trichloride product	1.8	(1.6)
$/kkg ($/ton) of raw waste	1,740	(1,580)

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* It is assumed that in return for absorbing transportation cost, the user of this material (Great Western Inorganics, Golden, Colorado) would not be charged for the reclaimed arsenic trichloride.

6.0 LAND DISPOSAL OPTION COSTS

6.1 Types of Land Disposal Facilities Considered

Two land disposal options are considered in this study; sanitary landfill and chemical landfill, both operated by the waste generator. The chemical landfills were designed for specific wastes.

The design bases used for sanitary landfills include disposing of solid wastes on land, spreading them in thin layers, compacting them to the smallest practical volume and covering them with soil at the end of each working day.

The design bases used for the chemical landfilling of the wastes differ from those for sanitary landfills in the following significant respects:

(1) Provision is made for lining the excavated areas with compacted colloidal clay (permeabilities in the range of 10^{-8} cm/sec).
(2) A synthetic membrane, selected as being impermeable and resistant to the waste being landfilled, is provided to line the landfill over the compacted clay.
(3) A leachate collection and monitoring system is provided.
(4) An impervious percolation barrier (compacted clay and a synthetic liner) is provided as cover at the completion of the landfill section, to minimize leachate formation.
(5) Provision is made for drumming, interlacing the drums with an absorbing material, or chemical fixing of liquid wastes prior to placing them in a chemical landfill.

6.1.1 Landfill Design Basis

Prior to estimating the capital cost and projected operating expenditures of a given landfill, the design basis considered in sizing the landfill must be known. The following outlines the design parameters considered in the sizing of the sanitary and chemical landfills in this study.

Volume Requirement

If the rate at which solid wastes are collected and the useful life of the proposed site is known, its capacity can be estimated. The ratio of the solid waste volume to fill material volume usually ranges between 4:1 and 3:1;[12] however, this ratio is primarily influenced by the thickness of the cover and the cell configuration of the landfill.

In this study, a 3:1 ratio of solid waste to fill volume, for both types of landfill operations, has been selected. An excavated depth of 20 feet was selected for the landfills and a compacted depth of 5 feet was chosen to provide adequate volume for intermediate covers and the final cover.

Area Requirement

In all cases, the landfill area is sized to accommodate twenty years of output of waste generated by the respective chemical manufacturing operations. An additional 50 or 30 percent area is provided for small sites (less than five acres of land requirement) and larger sites (more than five acres of land requirement), respectively, to accommodate a building for office space and employee facilities and roads that lead from the landfill entrance to the vicinity of the working area.

Landfill Method

The two basic landfilling methods used in the design of the landfills are trench and area; other approaches are only modifications of the above mentioned techniques. The trench method is used when the ground water is low and the soil is more than 6 feet deep. This latter method is best employed on flat or gently rolling land. The area method can be used on most topographies and is often used if large quantities of solid waste must be disposed.

The trench method was selected for this study. In this method of landfilling, waste is spread and compacted in an excavated trench. Cover material is taken from the spoil of the excavation and is, therefore, readily available. The spoil material not used for daily cover may be stockpiled and used later as an intermediate cover over the trench or used as the final cover over the completed landfill area.

Site Improvement and Grading

In both sanitary and chemical landfilling operations, site improvements are made to provide an orderly, sanitary and safe operation. This may simply involve the clearing of shrubs, trees, and other obstacles that could hinder vehicle travel and landfilling operation or it could involve the construction of buildings, roads and utilities.

In this study, provisions were made for excavation and grading of the land, that a trailer with toilet facility will be installed at each site, and the installation of electrical and telephone services.

Drumming of Liquids

All liquid wastes (aqueous solutions as well as organic liquids) are assumed to be packaged in 55-gallon drums prior to placing them in the landfills. For the chemical landfill option, provisions were made for either interlacing the drums with an absorbent or chemical fixation of the liquid in the drum to minimize the effects of drum failure.

Liner for Chemical Landfills

For the chemical landfill option, provisions for controlling the movement of fluids by a synthetic membrane were made. Since liners have been used successfully in wastewater-holding-and-treatment pond construction, they can also be used in solid waste disposal. A synthetic liner will overlay the clay layer to form a impermeable barrier to water seepage. Additionally, provisions have been made for preventing the infiltration of surface water through the cover material by providing a synthetic liner barrier over each section of the chemical landfill as it is closed.

Two different lining materials were selected for use in this study:

(1) a 30 mil reinforced Hypalon liner was specified for waste streams which are acidic in nature, and
(2) a 20 mil polyvinyl chloride liner was specified for the remaining waste streams because of its compatibility with a wide range of chemicals. When figuring the amount of material needed for lining the trench, a square trench configuration was assumed and enough material was included to cover the bottom as well as the sides of the trench. An additional 5 percent lining material was included as a provision for lining shrinkage, anchoring all around the trench berm, and for overlap loss for sealing.

Size of Operation

Definition of functions and evaluation of equipment performance must be matched with the size of the landfill to determine the type, number and size of machines needed. With the exception of land, the cost of equipment may be the greatest portion of initial expenditure for a landfill. Regardless of size of the operation, a landfill site should have the capability of excavating trenches, spreading and compacting solid waste and the cover material. However, small sites may find the cost of owning a small "dozer" or loader too high. In such cases, contract excavation, stockpiling and cover material spreading and compacting may prove to be more economical.

In this study, for waste streams 6, 8, 15, 17 and 18, which involve the disposal of less than 2 metric tons of waste per day, excavation stockpiling and cover material spreading and compacting by a contractor was assumed. For the remaining waste streams, it was assumed that the waste generator will purchase the equipment and provide the necessary labor.

Hours of Operation

The hours a sanitary landfill operates depends mainly on when the wastes are delivered, and generally this is done during normal working hours. In large cities, however, waste collection systems operate 24 hours a day. The usual landfill is normally operated on a 5 to 6 days per week and 8 to 10 hours per day basis.

In this study, an 8 hours per day and, in most cases, a 5 days per week landfill operation was assumed. However, to make the design basis and costs more realistic and close to the "actual life" operation, exceptions were made in the following cases:

Waste Stream No.	Industry	Days per Year of Operation
7	Titanium dioxide, Chloride Process	365
9	Hydrogen fluoride	365
13	Sodium silicofluoride	365
6	Chlor-alkali; Down's cell	12
15	Nickel sulfate	12
17	Phosphorus pentasulfide	12
18	Phosphorus trichloride	12

The quantity of waste generated by the last four industries is so small that it does not warrant the purchase of landfill equipment or the operation of the landfill on a continuous basis.

6.2 Cost Basis for Land Disposal Options

6.2.1 Capital Costs

Capital costs include those for land, area preparation, liners and leachate collection system, building and utilities installation and landfill equipment.

a. Land Cost

In view of the extreme variability in land costs, no attempt has been made to set different land values for each plant,

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industry or location. Instead, a constant value of \$12,350/hectare, recommended by EPA, (\$5,000/acre) was used throughout.

b. Area Grading and Preparation

A standardized landfill grading and preparation cost of \$3,000 per hectare (\$1,210 per acre) was used throughout this study for the sanitary landfill option.* A site preparation cost of \$6,700 per hectare (\$2,710/acre) was used for the chemical landfill option since fine grading and hand dressing will be required prior to liner installation.

c. Costs for Liners

A clay liner cost of \$18,500 per hectare (\$7,500/acre)was used throughout this study. Costs used for lining materials are given in Table 56. Additionally, a liner installation cost of \$0.14 per square meter (\$0.013/ft^2) was used.

d. Liner Cover Cost

It is assumed that the liner will be covered for protection by approximately 0.305 meter (1 ft.) of earth. Dumping and spreading costs are estimated at \$0.36 per square meter (\$0.30/yd^2).

e. Leachate Collection and Riser System Cost

This cost is taken as 15% of the total of all landfill capital costs (except for sludge moving equipment and building).

f. Building and Utilities Installation Costs

Costs for the following items were included in the building cost:

1. Trailer with toilet facilities:	\$6,000
2. Septic tank installation:	2,500
3. Installation of electrical and telephone services:	250
Total	\$8,750

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[*] Contractor estimates

TABLE 56

MATERIAL COSTS FOR PLASTIC LINERS (1976)[67]

	Cost for various size ranges, \$/sq m (\$/ft^2) of liner			
	93 to 930m^2 (1,000 to 10,000 ft^2	930 to 9,300m^2 (10,000 to 100,000 ft^2)	9,300 to 18,600m^2 (100,000 to 200,000 ft^2)	Over 18,600m^2 (Over 200,000 ft^2)
Polyvinyl Chloride, 30 mil	2.69 (0.25)	2.37 (0.22)	2.37 (0.22)	2.26 (0.21)
Hypalon, 30 mil (reinforced)	8.61 (0.80)	7.42 (0.69)	6.89 (0.64)	6.78 (0.63)

g. Landfill Equipment Costs

These costs were taken from Tables 9, 10 and 11, EPA report SW-65ts, USEPA, 1972 and updated to 1976 costs using appropriate Engineering Cost Indices.

6.2.2 Operating Expenses

Annual costs of operating a landfill facility include labor, supervision, drumming or contract excavation costs where applicable, maintenance, taxes and insurance, and power and energy. Operating costs combined with annualized capital costs give the total annual costs for the disposal operation. Operating cost factors specific to landfill operation are given below. Information on labor, maintenance, taxes and insurance and power are given in Appendix II of this report.

a. Drumming Costs

A cost of $10 was used for each 55-gallon capacity drum employed to store liquid wastes. These are unlined reconditioned steel drums, open-top with leverlock.

b. Cost of Absorbent and Chemical Fixation

A cost of $13.08 per cubic meter ($\$10/yd^3$) of absorbent was used for interlacing the drums containing liquid wastes prior to disposal in a chemical landfill. The chemical fixation cost was estimated at $0.05 per liter ($0.20/gallon) of waste.

c. Costs for Contract Stockpiling of Waste and Compacting of Cover Material

This cost was estimated at $6.1 per metric ton of waste ($5.5 per ton) for waste stockpiling and compacting.*

d. Energy Costs

A cost of 14.5¢ per liter of fuel (55¢/gal) was chosen for the diesel oil used for operating landfill equipment.

e. Building Utilities Costs

The utilities cost, including water, electric heat and telephone is assumed to average $100 per month.* For those plants which operate their landfill on a 12-day per year basis, an average cost of $100 per year was assumed.

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* Contractor estimate.

6.3 Costs for Plant Operated Sanitary and Chemical Landfills

Sanitary and chemical land disposal costs are presented in this section for the potentially hazardous wastes generated by inorganic chemicals industry. These costs are developed on the assumption that the landfills will be operated by the waste generator. A sample calculation of costs for the sanitary and chemical landfills is given in Appendix III of this report.

6.3.1 Streams 1 and 2 - Brine Purification Muds and Mercury-Bearing Sludge from Wastewater Treatment - Mercury Cell Process

Mercury-bearing wastes from the mercury cell process come from two general sources:

(1) brine purification muds containing low concentrations of mercury but often rather large in volume, and

(2) process wastes - often rich in mercury content but rather low in volume. These wastes include filter sludges, vessel cleanouts, leaks and spills. When treated they yield precipitates which are concentrated in mercury content, usually as the sulfide.

A survey of the mercury-bearing waste storage methods for seventeen of the twenty-eight mercury cell plants indicates that, in general, the brine muds are stored on ground, and the mercury-rich sludges from wastewater treatment are held in lined ponds.[93]

Table 57 presents the costs for the sanitary and chemical landfilling of these wastes by the typical mercury cell plant producing 250 kkg/day of chlorine.

In developing the capital cost for chemical landfilling of waste streams 1 and 2, a Hypalon liner was specified for use as the impermeable barrier in the landfill rather than a standard PVC liner. The choice of Hypalon is based on observed mercury cell industry practice.

Waste stream 1, brine purification muds, in both sanitary and chemical landfill operations, is first treated in a thickener, producing an underflow of 11 kkg/day (approximately 40% solids) which is suitable for landfilling. Capital cost figures shown in Table 57 include the cost of a thickener.

TABLE 57

COSTS FOR SANITARY AND CHEMICAL LANDFILL - MERCURY CELL PROCESS, ALKALIES & CHLORINE[1]

Waste Streams 1 & 2: Brine Purification Muds & Mercury Wastes from Waste Treatment & Cleaning Mercury Process.

Typical Plant Size: 250 metric tons of chlorine per day.

Potentially Hazardous Waste Streams:

Form: Sludges

Hazardous Components: 0.04 kkg/day - Mercury as metal, chloride and Sulfide.

Non-Hazardous Components: 4.25 kkg/day - $CaCO_3$, $Mg(OH)_2$, $BaSO_4$ & NaCl;
0.5 kkg/day - Graphite and filter aid;
14.75 kkg/day - water

Total Waste Stream: 4.75 kkg/day (dry basis)
19.5 kkg/day (wet basis)
12.0 kkg/day (wet basis, after thickening)

Type of Cost	Sanitary Landfill ($)	Chemical Landfill ($)
Capital Cost		
Site Cost (land and preparation)	48,440	60,140
Building Cost	8,750	8,750
Capital Equipment	93,650	530,015
TOTAL	150,840	598,905
Contingency	20,480	107,755
Total Investment	171,320	706,660
Operating Cost		
Labor (operating)	46,800	46,800
Labor (supervision)	23,400	23,400
Maintenance	4,920	21,550
Insurance and Taxes	6,850	28,265
Energy and Power	15,730	15,730
Utilities for the building	1,200	1,200
Drumming	--	—
Contractor	--	—
Total Operating Costs, excluding energy & utilities	81,970	120,015
Annual Investment Costs	19,990	105,190
Total Annual Costs	118,890	242,135
Cost/kkg of product	1.30	2.65
Cost/kkg of waste (dry basis)	68.60	140
Cost/kkg of waste (wet basis)	16.7	34

Notes: [1] It is assumed the landfill operates 8 hours a day and 260 days per year.

The costs are summarized as follows:

For sanitary landfilling:

Total Investment	$171,000
Annual Operating Costs:	
$/kkg ($/ton) of product	1.30 (1.18)
$/kkg ($/ton) of waste (dry basis)	69 (63)
$/kkg ($/ton) of waste (wet basis)	17 (15)

For chemical landfilling:

Total Investment	$706,700
Annual Operating Costs:	
$/kkg ($/ton) of product	2.65 (2.40)
$/kkg ($/ton) of waste (dry basis)	140 (127)
$/kkg ($/ton) of waste (wet basis)	34 (31)

6.3.2 Waste Streams 3, 4 and 5 - Chlorinated Hydrocarbons, Asbestos Separator Wastes and Lead-Bearing Sludges-Diaphragm Cell Process

Potentially hazardous wastes from the diaphragm cell process for production of chlorine are relatively small in volume but varied in nature. These wastes contain lead compounds, asbestos, and chlorinated hydrocarbons.

The diaphragm cell industry generally land disposes the lead-bearing sludges and asbestos wastes using contractors and privately operated landfill sites. Where appreciable amounts of chlorinated hydrocarbon waste are generated, these are generally drummed and then incinerated on or off-site, depending on the availability of a suitable incinerator with an HCl scrubber. Small amounts of chlorinated hydrocarbon waste are drummed and landfilled on or off-site.

Table 58 presents the costs for the sanitary and chemical landfilling of these three wastes. Costs are based on a typical diaphragm cell plant producing 450 kkg/day of chlorine.

The costs are summarized as follows:

For sanitary landfilling:

Total Investment	$135,000
Annual Operating Costs:	
$/kkg ($/ton) of product	0.68 (0.62)
$/kkg ($/ton) of waste (dry basis)	164 (149)
$/kkg ($/ton) of waste (wet basis)	47 (43)

TABLE 58

COSTS FOR SANITARY AND CHEMICAL LANDFILL - DIAPHRAGM CELL PROCESS, ALKALIES & CHLORINE[1]

Waste Streams 3,4 & 5 Chlorinated Hydrocarbons (HC), Asbestos Separator Wastes & Lead-Containing Sludge

Typical Plant Size: 450 metric tons of chlorine per day.

Potentially Hazardous Waste Streams:

Form: Sludge

Hazardous Components:
0.2 kkg/day - Chlorinated HC;
0.09 kkg/day - Lead (metal and carbonate);
0.225 kkg/day - Asbestos

Non-Hazardous Components:
1.35 kkg/day - Carbon and rubble;
4.66 kkg/day - water.

Total Waste Stream:
1.87 kkg/day (dry basis)
6.53 kkg/day (wet basis)

Type of Cost	Sanitary[2] Landfill ($)	Chemical[2] Landfill ($)
Capital Cost		
Site Cost (land and preparation)	27,200	33,770
Building Cost	8,750	8,750
Capital Equipment	81,200	191,930
TOTAL	117,150	234,450
Contingency	17,990	40,140
Total Investment	135,140	274,590
Operating Cost		
Labor (operating)	46,800	46,800
Labor (supervision)	23,400	23,400
Maintenance	4,320	9,630
Insurance and Taxes	5,410	10,980
Energy and Power	10,010	10,010
Utilities for the building	1,200	1,200
Drumming	3,370	3,370
Absorbent	—	5,010
Contractor	—	—
Total Operating Costs, excluding energy & utilities	83,290	99,190[3]
Annual Investment Costs	17,560	39,130
Total Annual Costs	112,060	149,000
Cost/kkg of product	0.68	0.91
Cost/kkg of waste (dry basis)	164.07	219.01
Cost/kkg of waste (wet basis)	47.03	62.77

Notes:

[1] It is assumed the landfill operates 8 hours a day and 260 days per year.

[2] Due to the nature of stream 3 , (HC), this waste is drummed before landfilled.

[3] Including cost of installment of absorbent, contractor estimate - \$10/yd.^{3}

For chemical landfilling:

Total Investment	$275,000	
Annual Operating Costs:		
$/kkg ($/ton) of product	0.91	(0.83)
$/kkg ($/ton) of waste (dry basis)	219	(199)
$/kkg ($/ton) of waste (wet basis)	63	(57)

In recognition of present industry practice, the cost of contract incineration has been calculated for the chlorinated hydrocarbon stream. A cost of 22¢/kg (10¢/lb) has been used as the total cost of contract incineration (including transportation)*. For waste stream 3, the annual cost of contract incineration is $16,000. Removing this stream from the sanitary and chemical landfill operations results in the following overall costs for the second land disposal option, e.g., sanitary landfill and chemical landfill for the lead and asbestos sludges and contract incineration for the chlorinated hydrocarbons:

For sanitary landfilling:

Total Investment	$134,000	
Annual Operating Costs:		
$/kkg ($/ton) of product	0.76	(0.69)
$/kkg ($/ton) of waste (dry basis)	183	(166)
$/kkg ($/ton) of waste (wet basis)	52	(47)

For chemical landfilling:

Total Investment	$268,000	
Annual Operating Costs:		
$/kkg ($/ton) of product	0.95	(0.86)
$/kkg ($/ton) of waste (dry basis)	228	(207)
$/kkg ($/ton) of waste (wet basis)	66	(60)

6.3.3 Waste Stream 6 - Metallic Sodium-Calcium Wastes - Down's Cell Process

In the Down's cell process, this waste is produced as a filter cake during metallic sodium purification. Of the five plants generating this waste, three use proprietary treatment processes to either recover metallic sodium values or render the waste non-hazardous. Two plants ocean dump this waste.

Because of the hazardous nature of sodium-calcium filter cake waste, this material cannot be landfilled. Any exposure to moisture can cause an explosive reaction. In this conceptual land disposal cost study, the waste is drummed before being placed in either the sanitary or chemical landfill. However, drums, even with linings, have a finite life in the landfill before moisture penetrates to the waste. It is unlikely, therefore, that containerized landfilling of the waste will ever be practiced by industry.

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* This estimate was obtained from Mr. M.A. Pierle, Manager of Environmental Protection and Manufacturing, Monsanto Ind. Chem. Co., St. Louis, Missouri.

Table 59 presents the cost for the sanitary and chemical landfilling of this waste.* In addition to the company-operated landfill options, the costs of a third option were calculated; sanitary landfilling by an outside contractor. In this option, it is assumed that the drummed wastes can be handled on a once a month basis by an outside contractor who provides his own labor and disposal equipment and uses the company-provided sanitary landfill facility. A contractual rate of $6.05/kkg ($5.50/ton) of waste was used for this option.** These costs are based on a typical Down's cell plant producing 140 kkg/day of metallic sodium. There is no moisture associated with this waste material, hence the unit costs are on a dry basis only.

For chemical landfilling:

Total Investment	$152,000
Annual Operating Costs:	
$/kkg ($/ton) of product	1.30 (1.18)
$/kkg ($/ton) of waste	100 (91)

For sanitary landfilling:

Total Investment	$103,000
Annual Operating	
$/kkg ($/ton) of product	0.94 (0.85)
$/kkg ($/ton) of waste	72 (65)

For sanitary landfilling (outside contractor operated):

Total Investment	$10,000
Annual Operating Costs:	
$/kkg ($/ton) of product	0.53 (0.48)
$/kkg ($/ton) of waste	41 (37)

6.3.4 Waste Stream 7 - Wastewater Treatment Sludges - Titanium Dioxide, Chloride Process

In the chloride process for the production of titanium dioxide, varying amounts of heavy metal chloride wastes are produced, depending on

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* In both options, it has been assumed that the landfill is operated one day per month (12 days per year).

** This rate is also used in other sections of the study where the outside contractor operated, company-owned landfill is used as an option. The rate is based on actual costs of landfill operation.

TABLE 59

COSTS FOR SANITARY AND CHEMICAL LANDFILL
DOWN'S CELL PROCESS, ALKALIES AND CHLORINE[1]

Waste Stream 6: Metallic Sodium / Calcium Filter Cake.

Typical Plant Size: 140 metric tons of Sodium per day.

Potentially Hazardous Waste Streams:

Form: Metal sludge (No water)

Hazardous Components: 1.82 kkg/day - Sodium and Calcium Metal.

Non-Hazardous Components: 0.1 kkg/day - CaO;
0.3 kkg/day - Na_2O;
Traces of NaCl and $CaCl_2$.

Total Waste Stream: 1.82 kkg/day(dry basis)[4]

Type of Cost	Sanitary[2] Landfill ($)	Chemical Landfill ($)	Sanitary Landfill Outside Contractor Operated
Capital Cost			
Site Cost (land and preparation)	10,350	12,860	10,350
Building Cost	8,750	8,750	—
Capital Equipment	68,500	107,460	—
TOTAL	87,600	129,070	10,350
Contingency	15,450	23,240	—
Total Investment	103,050	152,310	10,350
Operating Cost			
Labor (operating)	860	860	—
Labor (supervision)	430	430	—
Maintenance	3,710	5,580	—
Insurance and Taxes	4,120	6,090	104[3]
Energy and Power	590	590	—
Utilities for the building	100	100	—
Drumming	23,100	23,100	23,100
Absorbent	—	7,020	—
Contractor	—	—	4,020
Total Operating Costs, excluding energy & utilities	32,220	43,080	27,220
Annual Investment Costs	15,080	22,690	—
Total Annual Costs	47,990	66,460	27,220
Cost/kkg of product	0.94	1.30	0.53
Cost/kkg of waste (dry basis)	72.27	100.09	40.99
Cost/kkg of waste (wet basis)	—	—	—

Notes: [1] It is assumed the landfill operates 8 hours a day and 1 day per month.

[2] Due to the nature of this waste, waste is drummed before landfilled.

[3] Contractor estimate, taxes 1% of capital.

[4] This waste is a dry residue.

the titania feed stock used, i.e., ilmenite ore containing 45-65% titania versus rutile ore containing 90-95% titania. The non-titania portions of these ores consist primarily of iron and small amounts of aluminum, vanadium and chromium as the principal contaminants. Ilmenite ore generates large quantities of heavy metal wastes. Rutile ore generates approximately one fifth that of ilmenite. In this land disposal cost analysis, a conservative approach is taken in that the much larger waste stream (generated through the use of ilmenite as titania feed stock) was chosen as the stream that is to be land-disposed.

This waste is a sludge resulting from wastewater treatment. It is gelatinous in nature and is very difficult to dewater. This sludge is either stored in settling ponds or land dumped by the titanium dioxide producers (either on-site or off-site). One producer deep wells the heavy metal chloride wastes.

Table 60 presents the costs for the sanitary and chemical landfilling of this waste. These costs are based on a typical 100 kkg/day titanium dioxide chloride process plant. In addition to the standard cost items used in the respective capital cost estimates, a thickener and rotary vacuum filter are provided in each case to produce a sludge of approximately 25% solids.

The costs are summarized as follows:

For sanitary landfilling:

Total Investment	$3,150,000
Annual Operating Costs:	
$/kkg ($/ton) of product	29 (26)
$/kkg ($/ton) of waste (dry basis)	21 (19)
$/kkg ($/ton) of waste (wet basis)	1.1 (1.0)

For chemical landfilling:

Total Investment	$14,020,000
Annual Operating Costs:	
$/kkg ($/ton) of product	99 (90)
$/kkg ($/ton) of waste (dry basis)	71 (64)
$/kkg ($/ton) of waste (wet basis)	2.6 (2.4)

6.3.5 Waste Stream 8 - Wastewater Treatment Sludges - Chrome Color and Inorganic Pigment Manufacture

The manufacture of chrome pigments such as zinc yellow, chrome yellow, molybdate chrome orange, chrome green, and chrome oxide green produces

TABLE 60

COSTS FOR SANITARY AND CHEMICAL LANDFILL - TITANIUM DIOXIDE PIGMENT, CHLORIDE PROCESS[1]

Waste Stream 7B: Wastewater Treatment Sludges

Typical Plant Size: 100 metric tons of titanium dioxide pigment per day.

Potentially Hazardous Waste Streams:

Form: Sludge.

Hazardous Components: 0.13 kkg/day - $Cr(OH)_3$.

Non-Hazardous Components: 2.5 kkg/day - Ore Residue; 6.8 kkg/day - Coke; 0.6 kkg/day - Silica; 130 kkg/day - Misc. Hydroxide; 420 kkg/day - Water.

Total Waste Stream:
140 kkg/day (dry basis)
2800 kkg/day (wet basis)[2]
560 kkg/day (wet basis,after thickening)

Type of Cost	Sanitary Landfill ($)	Chemical Landfill ($)
Capital Cost		
Site Cost (land and preparation)	1,966,300	2,451,800
Building Cost	8,750	8,750
Capital Equipment	977,880	9,631,490
TOTAL	2,952,930	12,092,040
Contingency	197,330	1,928,050
Total Investment	3,150,260	14,020,100
Operating Cost		
Labor (operating)	341,640	341,640
Labor (supervision)	170,820	170,820
Maintenance	47,360	462,730
Insurance and Taxes	126,010	560,800
Energy and Power	188,710	188,710
Utilities for the building	1,200	1,200
Drumming	—	—
Contractor	—	—
Total Operating Costs, excluding energy & utilities	685,830	1,535,990
Annual Investment Costs	192,630	1,882,160
Total Annual Costs	1,068,360	3,608,050
Cost/kkg of product	29.27	98.85
Cost/kkg of waste (dry basis)	20.90	70.61
Cost/kkg of waste (wet basis)	1.05	2.55

Notes:

[1] It is assumed the landfill operates 8 hours a day and 365 days per year.

[2] Only one facility is known to thicken this waste sludge prior to disposal.

relatively large volumes of land-destined wastes containing lead, zinc and chromates. Iron blues manufacture contributes complex cyanide wastes.

Chrome pigments are usually made in integrated facilities flexible to shift from one product or combination of products to another. The composite waste stream characterized in this study represents the worst situation, since not all of the pigment plants produce all of the materials.

The chrome color and inorganic pigment manufacturing plants currently landfill the generated waste sludges either on or off-site.

Table 61 presents the costs for two land disposal options: sanitary landfill and chemical landfill. These costs are based on a typical plant producing 23 kkg/day of chrome and inorganic pigments.

The costs are summarized as follows:

For sanitary landfilling:

Total Investment	$117,000	
Annual Operating Costs:		
$/kkg ($/ton) of product	13	(11.8)
$/kkg ($/ton) of waste (dry basis)	129	(117)
$/kkg ($/ton) of waste (wet basis)	99	(90)

For chemical landfilling:

Total Investment	$159,000	
Annual Operating Costs:		
$/kkg ($/ton) of product	14	(12.7)
$/kkg ($/ton) of waste (dry basis)	140	(127)
$/kkg ($/ton) of waste (wet basis)	107	(97)

6.3.6 Waste Stream 9 - Gypsum Waste from Hydrofluoric Acid Manufacture

Gypsum (calcium sulfate) waste from hydrofluoric acid manufacture contains about 2-3 per cent by weight of calcium fluoride. Although some of this waste is used in road bed construction, the great majority is landfilled.

Table 62 presents the costs for the sanitary and chemical landfilling of this waste. These costs are based on a typical plant producing 64 kkg/day of hydrofluoric acid.

TABLE 61

COSTS FOR SANITARY AND CHEMICAL LANDFILL - CHROME PIGMENTS AND IRON BLUE.[1]

Waste Stream 8: Waste water treatment sludges.

Typical Plant Size: 23 metric tons of chrome pigments per day.

Potentially Hazardous Waste Streams:

Form: Sludge.

Hazardous Components: 0.2 kkg/day - $Cr(OH)_3$; 0.6 kkg/day - $PbCrO_4$; 0.06 kkg/day - $Pb(OH)_3$; 0.1 kkg/day - ZnO; 0.06 kkg/day - $Fe_4[Fe(CN)_6]_3$

Non-Hazardous Components: 1.28 kkg/day - Fe_2O_3, $CaSO_4$ & $Fe(OH)_3$; 0.7 kkg/day - Water.

Total Waste Stream: 2.3 kkg/day (dry basis)
3 kkg/day (wet basis)

Type of Cost	Sanitary Landfill ($)	Chemical Landfill ($)
Capital Cost		
Site Cost (Land and preparation)	9,190	11,410
Building Cost	8,750	8,750
Capital Equipment	81,200	113,880
TOTAL	99,140	134,040
Contingency	17,990	24,530
Total Investment	117,130	158,570
Operating Cost		
Labor (operating)	46,800	46,800
Labor (supervision)	23,400	23,400
Maintenance	4,320	5,890
Insurance and Taxes	4,685	6,340
Energy and Power	10,010	10,010
Utilities for the building	1,200	1,200
Drumming	—	—
Contractor	—	—
Total Operating Costs, excluding energy & utilities	79,200	82,430
Annual Investment Costs	17,560	23,960
Total Annual Costs	107,980	117,600
Cost/kkg of product	12.86	14.01
Cost/kkg of waste (dry basis)	128.62	140.00
Cost/kkg of waste (wet basis)	98.61	107.40

Notes: [1] It is assumed the landfill operates 8 hours a day and 260 days per year.

TABLE 62

COSTS FOR SANITARY AND CHEMICAL LANDFILL - HYDROFLUORIC ACID MANUFACTURE.[1]

Waste Stream 9: Gypsum Wastes

Typical Plant Size: 64 metric tons of hydrofluoric acid per day.

Potentially Hazardous Waste Streams:

Form: Sludge

Hazardous Components: 7 kkg/day, CaF_2.

Non-Hazardous Components: 233 kkg/day - $CaSO_4$ and silica;
60 kkg/day - Water.

Total Waste Stream: 240 kkg/day (dry basis)
300 kkg/day (wet basis)

Type of Cost Capital Cost	Sanitary Landfill ($)	Chemical Landfill ($)
Site Cost (land and preparation)	919,100	1,141,080
Building Cost	8,750	8,750
Capital Equipment	392,750	3,918,360
TOTAL	1,320,600	5,068,190
Contingency	80,300	785,420
Total Investment	1,400,900	5,853,610
Operating Cost		
Labor (operating)	197,100	197,100
Labor (supervision)	98,600	98,600
Maintenance	19,270	188,500
Insurance and Taxes	56,040	234,140
Energy and Power	106,400	106,400
Utilities for the building	1,200	1,200
Drumming	—	—
Contractor	—	—
Total Operating Costs, excluding energy & utilities	371,010	718,340
Annual Investment Costs	78,390	766,730
Total Annual Costs	557,000	1,592,700
Cost/kkg of product	23.84	68.18
Cost/kkg of waste (dry basis)	6.36	18.18
Cost/kkg of waste (wet basis)	5.09	14.54

Notes: [1] It is assumed the landfill operates 8 hours a day and 365 days per year.

The costs are summarized as follows:

For sanitary landfilling:

Total Investment	$1,401,000	
Annual Operating Costs:		
$/kkg ($/ton) of product	24	(21.8)
$/kkg ($/ton) of waste (dry basis)	6.4	(5.8)
$/kkg ($/ton) of waste (wet basis)	5.1	(4.6)

For chemical landfilling:

Total Investment	$5,854,000	
Annual Operating Costs:		
$/kkg ($/ton) of product	68	(62)
$/kkg ($/ton) of waste (dry basis)	18	(16.3)
$/kkg ($/ton) of waste (wet basis)	15	(13.6)

6.3.7 Waste Stream 11 - Wastewater Treatment Sludges from Aluminum Fluoride Manufacture

Land-destined wastes from the manufacture of aluminum fluoride consist of aluminum fluoride, calcium fluoride, calcium sulfate and lime. Since aluminum fluoride is often produced in complexes producing other fluoride chemicals, the wastes are likely to be combined with much larger quantities of similar wastes from other processes. These wastes are currently landfilled.

Table 63 presents the costs for the sanitary and chemical landfilling of this waste. These costs are based on a typical plant producing 145 kkg/day of aluminum fluoride.

The costs are summarized as follows:

For sanitary landfilling:

Total Investment	$282,000	
Annual Operating Costs:		
$/kkg ($/ton) of product	2.9	(2.7)
$/kkg ($/ton) of waste (dry basis)	16	(14.5)
$/kkg ($/ton) of waste (wet basis)	13	(11.8)

TABLE 63

COSTS FOR SANITARY AND CHEMICAL LANDFILL - ALUMINUM FLUORIDE MANUFACTURE.[1]

Waste Stream 11: Wastewater Treatment Sludges

Typical Plant Size: 145 metric tons of aluminum fluoride per day.

Potentially Hazardous Waste Streams:

Form: Sludge

Hazardous Components: 12 kkg/day - CaF_2.

Non-Hazardous Components:
10 kkg/day - $CaSO_4$;
4 kkg/day - Hydrated lime;
7 kkg/day - Water.

Total Waste Stream:
26 kkg/day (dry basis)
33 kkg/day (wet basis)

Type of Cost	Sanitary Landfill ($)	Chemical Landfill ($)
Capital Cost		
Site Cost (land and preparation)	100,780	125,160
Building Cost	8,750	8,750
Capital Equipment	142,000	549,400
TOTAL	251,530	683,310
Contingency	30,150	111,630
Total Investment	281,680	794,940
Operating Cost		
Labor (operating)	56,160	56,160
Labor (supervision)	28,080	28,080
Maintenance	7,240	26,800
Insurance and Taxes	11,270	31,800
Energy and Power	21,450	21,450
Utilities for the building	1,200	1,200
Drumming	—	—
Contractor	—	—
Total Operating Costs, excluding energy & utilities	102,740	142,830
Annual Investment Costs	29,430	109,000
Total Annual Costs	154,820	274,500
Cost/kkg of product	2.93	5.19
Cost/kkg of waste (dry basis)	16.31	28.92
Cost/kkg of waste (wet basis)	12.85	22.79

Notes: [1] It is assumed the landfill operates 8 hours a day and 260 days per year.

For chemical landfilling:

Total Investment	$795,000
Annual Operating Costs:	
$/kkg ($/ton) of product	5.2 (4.7)
$/kkg ($/ton) of waste (dry basis)	29 (26)
$/kkg ($/ton) of waste (wet basis)	23 (21)

6.3.8 Waste Stream 13 - Fluoride Wastes from Sodium Silicofluoride Manufacture

There are three plants in the United States producing this chemical. Each handles their wastes differently:

Plant 1 - Has no attributable land-destined wastes since it recycles unused portions of its raw material.
Plant 2 - Deep wells all wastes.
Plant 3 - Treats its wastes as a small portion of an overall waste stream from the chemical complex.

The small number of plants and the different waste treatment/disposal technology used at each site reduces the significance of the "typical plant" for this industry segment.

Table 64 presents the costs for the sanitary and chemical landfilling of this waste. These costs are based on a plant producing 45 kkg/day of sodium silicofluoride.

The costs are summarized as follows:

For sanitary landfilling:

Total Investment	$228,000
Annual Operating Costs:	
$/kkg ($/ton) of product	11 (10)
$/kkg ($/ton) of waste (dry basis)	73 (66)
$/kkg ($/ton) of waste (wet basis)	22 (20)

For chemical landfilling:

Total Investment	$691,000
Annual Operating Costs:	
$/kkg ($/ton) of product	18 (16.3)
$/kkg ($/ton) of waste (dry basis)	115 (104)
$/kkg ($/ton) of waste (wet basis)	35 (32)

TABLE 64

COSTS FOR SANITARY AND CHEMICAL LANDFILL - SODIUM SILICOFLUORIDE MANUFACTURE[1]

Waste Streams 13: Calcium Fluoride Containing Wastes

Typical Plant Size: 45 metric tons of sodium silicofluoride per day

Potentially Hazardous Waste Streams:

Form: Sludge

Hazardous Components: 2.6 - 4.5 kkg/day - CaF_2

Non-Hazardous Components: 2.5 - 4.4 kkg/day - silica, salt & hydrated lime.
16 kkg/day -water.

Total Waste Stream: 7 kkg/day (dry basis)
23 kkg/day (wet basis)

Type of Cost	Sanitary Landfill ($)	Chemical Landfill ($)
Capital Cost		
Site Cost (land and preparation)	93,200	115,650
Building Cost	8,750	8,750
Capital Equipment	103,700	470,400
TOTAL	205,650	594,800
Contingency	22,490	95,830
Total Investment	228,140	690,630
Operating Cost		
Labor (operating)	78,840	78,840
Labor (supervision)	39,420	39,420
Maintenance	5,400	23,000
Insurance and Taxes	9,130	27,620
Energy and Power	30,110	30,110
Utilities for the building	1,200	1,200
Drumming	—	—
Contractor	—	—
Total Operating Costs, excluding energy & utilities	132,780	168,900
Annual Investment Costs	21,950	93,550
Total Annual Costs	186,040	293,700
Cost/kkg of product	11.33	17.88
Cost/kkg of waste (dry basis)	72.82	114.97
Cost/kkg of waste (wet basis)	22.17	34.99

Notes: [1] It is assumed the landfill operates 8 hours a day and 365 days per year.

6.3.9 Waste Stream 14 - Chromium Contaminated Wastewater Treatment Sludges from Chromate Manufacture

Chromite ore is the source for the basic chromate chemicals such as sodium chromate, sodium dichromate, potassium dichromate, and chromic acid. The ore, which is generally of low purity, produces a large volume of gangue and land-destined wastes. The ore residues, along with much smaller quantities of water treatment sludges, and residual water soluble chromates constitute the solid waste which is approximately 1,700-3,500 kg/kkg of product.

Table 65 presents the costs for the sanitary and chemical landfilling of this waste. These costs are based on a typical plant producing 182 kkg/day of chromate chemicals.

The costs are summarized as follows:

For sanitary landfilling:

Total Investment	$1,010,000	
Annual Operating Costs:		
$/kkg ($/ton) of product	7.7	(7.0)
$/kkg ($/ton) of waste (dry basis)	9.4	(8.5)
$/kkg ($/ton) of waste (wet basis	7.0	(6.4)

For chemical landfilling:

Total Investment	$3,688,000	
Annual Operating Costs:		
$/kkg ($/ton) of product	15	(13.6)
$/kkg ($/ton) of waste (dry basis)	19	(17.2)
$/kkg ($/ton) of waste (wet basis)	14	(12.7)

6.3.10 Waste Stream 15 - Nickel-containing Wastes from Wastewater Treatment, Nickel Sulfate Manufacture

Only one plant manufacturing nickel sulfate is known to use impure nickel feedstocks. This process generates purification muds and wastewater treatment sludges.

Due to the small quantity of waste generated, costs have also been developed based on contract disposal in a company-provided sanitary landfill. The landfill in each case is assumed to operate one day per month.

TABLE 65

COSTS FOR SANITARY AND CHEMICAL LANDFILL - CHROMATE MANUFACTURE.[1]

Waste Stream 14: Chromate Contaminated Wastewater Treatment Sludge

Typical Plant Size: 182 metric tons of chromate per day

Potentially Hazardous Waste Streams:

Form:	Muds and sludges
Hazardous Components:	0.025 kkg/day - $Cr(OH)_3$; 0.005 kkg/day - Chromate.
Non-Hazardous Components:	150 kkg/day - Ore residue includes oxide and carbonates of Fe, Si and Mg, plus Ca Salts & $Al(OH)_3$ 50 kkg/day - Water.
Total Waste Stream:	150 kkg/day (dry basis) 200 kkg/day (wet basis)

Type of Cost	Sanitary Landfill ($)	Chemical Landfill ($)
Capital Cost		
Site Cost (land and preparation)	550,500	683,350
Building Cost	8,750	8,750
Capital Equipment	374,500	2,494,700
TOTAL	933,750	3,186,800
Contingency	76,650	500,690
Total Investment	1,010,400	3,687,500
Operating Cost		
Labor (operating)	131,000	131,000
Labor (supervision)	65,500	65,500
Maintenance	18,400	120,170
Insurance and Taxes	40,420	147,500
Energy and Power	72,900	72,900
Utilities for the building	1,200	1,200
Drumming	—	—
Contractor	—	—
Total Operating Costs, excluding energy & utilities	255,320	464,200
Annual Investment Costs	182,300	488,800
Total Annual Costs	511,720	1,027,100
Cost/kkg of product	7.70	15.46
Cost/kkg of waste (dry basis)	9.35	18.76
Cost/kkg of waste (wet basis)	7.01	14.07

Notes: [1] It is assumed the landfill operates 8 hours a day and 250 days per year.

These costs were determined based on a typical 9 kkg/day nickel sulfate plant and are presented in Table 66.

The costs are summarized as follows:

For sanitary landfilling:

Total Investment	$86,400
Annual Operating Costs:	
$/kkg ($/ton) of product	11 (10)
$/kkg ($/ton) of waste (dry basis)	196 (178)
$/kkg ($/ton) of waste (wet basis)	98 (89)

For chemical landfilling:

Total Investment	$118,000
Annual Operating Costs:	
$/kkg ($/ton) of product	13 (11.8)
$/kkg ($/ton) of waste (dry basis)	237 (215)
$/kkg ($/ton) of waste (wet basis)	118 (107)

For sanitary landfilling (outside contractor operated):

Total Investment	$ 5,000
Annual Operating Costs:	
$/kkg ($/ton) of product	4.5 (4.1)
$/kkg ($/ton) of waste (dry basis)	81 (73)
$/kkg ($/ton) of waste (wet basis)	41 (37)

6.3.11 Waste Streams 16A and 16B - Fluoride Waste and Phossy Water - Phosphorus Manufacture

Potentially hazardous land-destined wastes from elemental phosphorus manufacture are generated from air and water treatment operations and process components.

To protect the air quality and effluent water quality it is necessary to reduce or remove the following wastes:

a) suspended phosphorus from the phossy water,
b) fluorides, dusts and other air pollutant components by scrubbing the gas from the ore calcining and furnace vents.

TABLE 66

COSTS FOR SANITARY AND CHEMICAL LANDFILL - NICKEL SULFATE MANUFACTURE.[1]

Waste Stream 15: Nickel Containing Wastes from Wastewater Treatment

Typical Plant Size: 9 metric tons of nickel sulfate per day

Potentially Hazardous Waste Streams:

Form: Sludge

Hazardous Components: 0.7 kkg/day - $Ni(OH)_2$

Non-Hazardous Components: 0.5 kkg/day - Filter aid; small amount - organic material; 0.5 kkg/day - water

Total Waste Stream: 0.5 kkg/day (dry basis); 1 kkg/day (wet basis)

Type of Cost	Sanitary Landfill ($)	Chemical Landfill ($)	Drum & Contractor Labor ($)
Capital Cost			
Site Cost (land and preparation)	5,440	6,800	5,440
Building Cost	8,750	8,750	—
Capital Equipment	58,700	84,210	—
TOTAL	72,900	99,760	5,440
Contingency	13,500	18,600	—
Total Investment	86,400	118,360	5,440
Operating Cost			
Labor (operating)	1,730	1,730	—
Labor (supervision)	860	860	—
Maintenance	3,240	4,460	—
Insurance and Taxes	3,460	4,730	540[2]
Energy and Power	1,060	1,060	—
Utilities for the building	100	100	—
Drumming	12,130	12,130	12,130
Contractor	—	—	2,210
Total Operating Costs, excluding energy & utilities	21,420	23,920	14,880
Annual Investment Costs	13,200	18,150	—
Total Annual Costs	35,800	43,230	14,880
Cost/kkg of product	10.88	13.15	4.53
Cost/kkg of waste (dry basis)	195.84	236.84	81.31
Cost/kkg of waste (wet basis)	97.92	118.42	40.66

Notes:

[1] It is assumed the landfill operates 8 hours a day and one day per month.

[2] A tax rate of 1% on invested capital for land has been estimated.

There are a variety of methods used for treating the phossy water including pond settling, clarifying, filtering and centrifuging. The latter three treatment methods usually involve direct return of collected phosphorus to the process. Phosphorus settled to the bottom of ponds is often allowed to remain there indefinitely.

The fluorides removed in the scrubbers are treated with lime and also allowed to settle in ponds. Because of the large quantities of settled wastes, fairly frequent pond cleaning is practiced. The calcium fluoride sludges are usually landfilled.

In this study involving the two land disposal options, it is assumed that the phossy water sludge (produced after suitable settling in ponds) would be drummed for safety reasons.* It is also assumed that chemical fixation of this sludge would be employed in the chemical landfill option. Table 67 presents the costs for the sanitary and chemical landfilling of these wastes. The two streams (phossy water and calcium fluoride sludge) have been considered as a combined stream for costing purposes. These costs are based on a typical plant producing 136 kkg/day of elemental phosphorus.

The costs are summarized as follows:

For sanitary landfilling:

Total Investment	$635,000
Annual Operating Costs:	
$/kkg ($/ton) of product	11 (10)
$/kkg ($/ton) of waste (dry basis)	30 (27)
$/kkg ($/ton) of waste (wet basis)	15 (13.6)

For chemical landfilling:

Total Investment	$4,993,000
Annual Operating Costs:	
$/kkg ($/ton) of product	42 (38)
$/kkg ($/ton) of waste (dry basis)	108 (98)
$/kkg ($/ton) of waste (wet basis)	55 (50)

Since an alternate treatment process involving resource recovery has been developed for waste stream 16B (Section 5.1.13), a set of costs for the landfilling of this stream alone have also been determined for comparison

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* Elemental phosphorus in this sludge is pyrophoric once the s[illegible] is allowed to dry.

TABLE 67

COSTS FOR SANITARY AND CHEMICAL LANDFILL - PHOSPHORUS MANUFACTURE.[1]

Waste Streams 16A&16B: Calcium Fluoride and Phossy Water Waste Streams

Typical Plant Size: 136 metric tons of phosphorus per day.

Potentially Hazardous Waste Streams:

Form: Sludge

Hazardous Components: 1.2 kkg/day - Phosphorus; 8.8 kkg/day - CaF_2.

Non-Hazardous Components: 1.8 kkg/day CaO; 5.0 kkg/day - SiO_2; 4.5 kkg/day - $Ca_3(PO4)_2$; 30.6 kkg/day - $CaSO_4$; 0.6 kkg/day - Suspended Solids.

Total Waste Stream: 52.5 kkg/day (dry basis)
102.6 kkg/day (wet basis)

Type of Cost	Sanitary Landfill ($)	Chemical Landfill ($)
Capital Cost		
Site Cost (land and preparation)	409,860	508,900
Building Cost	8,750	8,750
Capital Equipment	179,050	3,727,700
TOTAL	597,660	4,245,300
Contingency	37,560	747,280
Total Investment	635,220	4,992,600
Operating Cost		
Labor (operating)	93,600	93,600
Labor (supervision)	46,800	46,800
Maintenance	9,010	179,400
Insurance and Taxes	25,410	220,060
Energy and Power	50,050	50,050
Utilities for the building	1,200	1,200
Drumming	307,270	307,720
Chemical Fixation	—	338,000
Absorbent	—	95,400
Contractor	—	—
Total Operating Costs, excluding energy & utilities	482,100	1,280,500
Annual Investment Costs	36,670	729,500
Total Annual Costs	570,000	2,061,250
Cost/kkg of product	11.48	41.52
Cost/kkg of waste (dry basis)	29.75	107.56
Cost/kkg of waste (wet basis)	15.22	55.04

Notes: [1] It is assumed the landfill operates 8 hours a day and 260 days per year.

purposes. Table 68 presents land disposal costs for this waste. As discussed, it is assumed that this waste would be drummed and subjected to chemical fixation prior to disposal in the chemical landfill. The costs summarized below, are based on a typical plant producing 136 kkg/day of elemental phosphorus.

For sanitary landfilling:

Total Investment	\$208,000	
Annual Operating Costs:		
\$/kkg (\$/ton) of product	8.0	(7.3)
\$/kkg (\$/ton) of waste (dry basis)	608	(551)
E/kkg (\$/ton) of waste (wet basis)	60	(54)

For chemical landfilling:

Total Investment	\$1,702,420	
Annual Operating Costs:		
\$/kkg (\$/ton) of product	24	(21.8)
\$/kkg (\$/ton) of waste (dry basis)	1,810	(1,640)
\$/kkg (\$/ton) of waste (wet basis)	178	(161)

6.3.12 Waste Stream 17 - Arsenic and Phosphorus Wastes - Phosphorus Pentasulfide Manufacture

Arsenic pentasulfide is present in the still bottoms from phosphorus pentasulfide manufacture. The still bottoms also contain unreacted phosphorus and phosphorus pentasulfide. The amount of the waste generated is small and it is normally land disposed.

Costs were developed for sanitary and chemical landfilling of this waste. Included also is the cost for contract disposal in a company-provided sanitary landfill. In all cases, the waste is drummed prior to landfilling. It is assumed that the landfill would operate one day per month (12 days per year).

Table 69 presents costs for the three disposal options. The costs are based on a typical plant producing 55,000 kkg/year of phosphorus pentasulfide. There is no moisture associated with this waste material, hence the unit cost of waste is on a dry basis.

The costs are summarized as follows:

For sanitary landfilling:

Total Investment	\$72,000	
Annual Operating Costs:		
\$/kkg (\$/ton)of product	0.43	(0.39)
\$/kkg (\$/ton) of waste	215	(195)

TABLE 68

COSTS FOR SANITARY AND CHEMICAL LANDFILL - PHOSPHORUS MANUFACTURE

Waste Stream No. 16B: Phossy water waste stream

Typical Plant Size: 136 metric tons of phosphorus per day.

Potentially Hazardous Waste Streams:

Form: Sludge

Hazardous Components: 1.2 kkg/day phosphorus

Non-Hazardous Components: 0.6 kkg/day suspended solids; 16.6 kkg/day water

Total Waste Stream: 1.8 kkg/day(dry basis); 18.3 kkg/day (wet basis)

Type of Cost Capital Cost	Sanitary Landfill[2] ($)	Chemical Landfill ($)
Site Cost (land and preparation)	137,860	171,160
Building Cost	8,750	8,750
Capital Equipment	49,700	1,267,300
TOTAL	196,310	1,447,210
Contingency	11,690	255,210
Total Investment	208,000	1,702,420
Operating Cost		
Labor (operating)	37,440	37,440
Labor (supervision)	18,720	18,720
Maintenance	2,810	61,250
Insurance and Taxes	8,320	68,100
Energy and Power	12,870	12,870
Utilities for the building	1,200	1,200
Drumming	307,300	307,300
Chemical Fixation	—	338,000
Absorbent	—	95,400
Contractor	—	—
Total Operating Costs, excluding energy & utilities	374,560	926,180
Annual Investment Costs	11,410	249,140
Total Annual Costs	400,040	1,189,400
Cost/kkg of product	8.06	23.96
Cost/kkg of waste (dry basis)	608.89	1,810.33
Cost/kkg of waste (wet basis)	59.89	178.05

Notes:

[1] It is assumed the landfill operates 8 hours a day and 260 days per year.

[2] Due to the nature of this waste, the waste is drummed before landfilled.

TABLE 69

COSTS FOR SANITARY AND CHEMICAL LANDFILL - PHOSPHORUS PENTASULFIDE MANUFACTURE.[1]

Waste Stream 17: Arsenic and Phosphorus Waste.

Typical Plant Size: 55,000 metric tons of phosphorus pentasulfide

Potentially Hazardous Waste Streams:

Form: Dry residues and dust.

Hazardous Components: 3 kkg/yr - As_2S_3;
8 kkg/day - Phosphorus & phosphorus sulfide

Non-Hazardous Components: 108 kkg/yr - glassy phosphate & Fe_2S_3.

Total Waste Stream: 110 kkg/yr (dry basis)[2]

Type of Cost	Sanitary Landfill ($)	Chemical Landfill ($)	Drum & Contractor Labor ($)
Capital Cost			
Site Cost (land and preparation)	1,900	2,350	1,900
Building Cost	8,750	8,750	—
Capital Equipment	49,700	57,200	—
TOTAL	60,350	68,300	1,900
Contingency	11,700	13,200	—
Total Investment	72,050	81,500	1,900
Operating Cost			
Labor (operating)	1,300	1,300	—
Labor (supervision)	650	650	—
Maintenance	2,810	3,170	—
Insurance and Taxes	2,880	3,260	20[3]
Energy and Power	260	260	—
Utilities for the building	100	100	—
Drumming Costs	4,260	4,260	4,260
Contractor	—	—	660
Total Operating Costs, excluding energy & utilities	11,890	12,630	4,940
Annual Investment Costs	11,420	12,870	—
Total Annual Costs	23,670	25,870	4,940
Cost/kkg of product	0.43	0.47	0.09
Cost/kkg of waste (dry basis)	215.18	236.21	45.11
Cost/kkg of waste (wet basis)			

Notes:

[1] It is assumed the landfill operates 8 hours a day and one day per month.

[2] This waste stream is a dry residue.

[3] A tax rate of 1% on invested capital for land has been assumed.

For sanitary landfilling (outside contractor operated):

Total Investment	$1,900	
Annual Operating Costs		
$/kkg ($/ton) of product	0.09	(0.08)
$/kkg ($/ton) of waste	45	(41)

For chemical landfilling:

Total Investment	$82,000	
Annual Operating Costs:		
$/kkg ($/ton) of product	0.47	(0.43)
$/kkg ($/ton) of waste	236	(214)

6.3.13 Waste Stream 18 - Arsenic Chloride Waste - Phosphorus Trichloride Manufacture

Arsenic trichloride is present in the still bottoms from phosphorus trichloride manufacture. The still bottoms also contain glassy phosphates and ferric chloride. This waste is normally land disposed.

Costs have been developed for sanitary and chemical landfilling of this waste. Also included is the cost for contract disposal in a company-provided sanitary landfill. In all cases, the waste is drummed. It is assumed that the landfill would operate one day per month (12 days per year).

Table 70 presents costs for the three cases discussed above. These costs are based on a typical plant producing 58,000 kkg/yr of phosphorus trichloride. This waste stream is always dry.

The costs are summarized as follows:

For sanitary landfilling:

Total Investment	$71,000	
Annual Operating Costs:		
$/kkg ($/ton) of product	0.36	(0.33)
$/kkg ($/ton) of waste	362	(328)

For sanitary landfilling (outside contractor operated):

Total Investment	$780	
Annual Operating Costs:		
$/kkg ($/ton) of product	0.04	(0.036)
$/kkg ($/ton) of waste	36	(33)

TABLE 70

COSTS FOR SANITARY AND CHEMICAL LANDFILL - PHOSPHORUS TRICHLORIDE MANUFACTURE.[1]

Waste Stream 18: Arsenic Chloride Waste.

Typical Plant Size: 58,000 metric tons of phosphorus trichloride per year.

Potentially Hazardous Waste Streams:

Form: Dry residue

Hazardous Components: 3 kkg/yr - $AsCl_3$.

Non-Hazardous Components: 57 kkg/yr - Glassy phosphate & $FeCl_3$.

Total Waste Stream: 60 kkg/yr (dry basis)[2]

Type of Cost	Sanitary Landfill ($)	Chemical Landfill ($)	Drum & Contractor Labor ($)
Capital Cost			
Site Cost (land and preparation)	930	970	780
Building Cost	8,750	8,750	—
Capital Equipment	49,700	55,100	—
TOTAL	59,380	64,820	780
Contingency	11,700	12,770	—
Total Investment	71,080	77,590	780
Operating Cost			
Labor (operating)	1,300	1,300	—
Labor (supervision)	650	650	—
Maintenance	2,810	3,070	—
Insurance and Taxes	2,840	3,100	8[3]
Energy and Power	260	260	—
Utilities for the building	100	100	—
Drumming	1,730	1,750	1,750
Contractor	—	—	350
Total Operating Costs, excluding energy & utilities	9,340	9,860	2,110
Annual Investment Costs	11,420	12,500	—
Total Annual Costs	21,130	22,700	2,110
Cost/kkg of product	0.36	0.39	0.04
Cost/kkg of waste (dry basis)	361.80	388.58	36.01
Cost/kkg of waste (wet basis)			

Notes:

[1] It is assumed the landfill operates 8 hours a day and one day per month.

[2] This waste is a dry residue.

[3] Contractor estimates taxes 1%.

For chemical landfilling:

Total Investment	$78,000	
Annual Operating Costs:		
$/kkg ($/ton) product	0.39	(0.35)
$/kkg ($/ton) waste	389	(353)

7.0 COMPARISON STUDIES

7.1 Capital Investment and Operating Cost Comparisons Between Alternate Treatment Methods and the Two Land Disposal Options

Tables 71 through 83 present costs (capital investment and annual operating) and energy requirements for the alternate treatment processes as compared to the plant operated landfill options for the waste streams under study.

For thirteen of the fifteen waste streams involved in this study, sanitary landfill operations are significantly lower in capital outlays than either the chemical landfill or alternate treatment processes. For one of the waste streams (stream 11), within the error of cost estimation, the capital outlays are approximately equal for the sanitary landfill and the treatment process. For waste stream 18, the treatment process (system 18100) shows a significant advantage in the amount of capital outlay over both sanitary and chemical landfill options; and for five other streams (7, 9, 13, 15 and 16A and 16B combined), the treatment process shows an advantage in the amount of capital outlay over the respective chemical landfill option. However, the high annual operating cost estimated for the treatment processes negates the capital outlay cost advantages for these six waste streams.

Table 84 summarizes the ratio of annual operating costs and energy requirements for the treatment systems as compared to the two land disposal options. As indicated, it is only for waste stream 16B that the annual operating cost of waste treatment system (16B100) is significantly lower than the land disposal options. For waste streams 1 and 2, the annual operating cost of treatment system 01200 is equivalent to that of the chemical landfill option. For the remaining waste streams, the annual operating cost ratios for the treatment system compared to land disposal options range between a low of 1.2 for system 08200 to a high of 47 for system 06100 favoring land disposal options.

With respect to the energy requirements, system 01100 and 08200 have approximately the same energy consumption as the respective landfill options. However, the remaining treatment systems have higher energy requirements ranging from a low ratio of 2 to a high of 260 favoring the land disposal options.

In the following sections, comparisons by industrial category are made with respect to annual operating cost* per kkg of product, and total annual energy consumption (equivalent BTU basis).

7.1.1 Chlor-Alkali Manufacturing Plants

a. Mercury Cell Operations - Waste Streams 1 and 2

Table 71 indicates annual operating cost ratios of 2 to 5 favoring sanitary landfill use as compared to alternate treatment processes (systems 01100 and 01200). Alternate treatment process 01100 demonstrates the highest annual operating cost while the annual operating cost for the second alternate treatment process (system 01200) is approximately equivalent to that of the chemical landfill option (within the error of cost estimation).

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* Includes the annualized capital cost.

Further, Table 71 indicates a total energy consumption ratio of approximately 6 favoring the landfill options when they are compared to process 01200. Process 01100 uses far less energy being approximately equivalent to that of the landfill options.

b. Diaphragm Cell Operations - Waste Streams 4 and 5

Table 72 indicates annual operating cost ratios of 2 to 3 favoring the land disposal options as compared to the combined alternate treatment processes 04100 and 05100. The costs incurred for these two treatment processes are combined for purposes of comparison since waste streams 4 and 5 are generated at the same plant site. The total annual energy consumption is approximately twice as much for the alternate treatment processes as compared to the land disposal options.

7.1.2 Sodium Manufacturing Plants - Waste Stream 6

Table 73 indicates an annual operating cost ratio of approximately 40 favoring the plant operated landfills when they are compared to the treatment process 06100. This ratio would be even greater (~80) if the sanitary landfill is operated by an outside contractor. The total annual energy requirement is appreciably greater (by a factor of ~260) for the alternate treatment process as compared to the landfill options. It should be pointed out, however, that it is unlikely that land disposal would be used for this waste stream since any inadvertent exposure to moisture can cause an explosive reaction. This was discussed in detail in Section 6.3.3.

7.1.3 Chloride Process, Titanium Dioxide Plants - Waste Stream 7B

Table 74 indicates annual operating cost ratios of 2 to 7 favoring the land disposal options when they are compared to the alternate treatment process 07100. The annual energy requirement of system 07100 is greater by a factor of approximately 30 compared to the two landfill options.

7.1.4 Chrome Color and Inorganic Pigments Manufacturing Plants - Waste Stream 8

Table 75 indicates annual operating cost ratios of 1.3 to 3 favoring the land disposal options when they are compared to the two alternate treatment processes 08200 and 08100, respectively. The total annual energy requirement is approximately threefold greater for process 08100 compared to the two land disposal options. However, the energy requirements for process 08200 are approximately equal to that of the two land disposal options.

7.1.5 Hydrofluoric Acid Manufacturing Plants - Waste Stream 9

Table 76 indicates annual operating cost ratios of 5 to 15 favoring the two land disposal options when they are compared to the alternate treatment process 09100. The total annual energy requirement for process 09100 is approximately eightfold greater than the two land disposal options.

7.1.6 Aluminum Fluoride Manufacturing Plants - Waste Stream 11

Table 77 indicates annual operating cost ratios of 3 to 6 favoring the two land disposal options when they are compared to the alternate treatment process 11100. The total annual energy requirement is approximately fourfold greater for process 11100 compared to the two land disposal options.

7.1.7 Sodium Silicofluoride Manufacturing Plants - Waste Stream 13

Table 78 indicates annual operating cost ratios of 2 to 3 favoring the two land disposal options when they are compared to the alternate treatment process 13100. The total annual energy requirement for process 13100 is approximately twofold greater than that required for the land disposal options.

7.1.8 Chromates Manufacturing Plants - Waste Stream 14

Table 79 indicates annual operating cost ratios of 4 to 8 favoring the two land disposal options when they are compared to the alternate treatment process 14100. The total annual energy requirement is approximately thirteenfold greater for process 14100 compared to the two land disposal options.

7.1.9 Nickel Sulfate Manufacturing Plants - Waste Stream 15

Table 80 indicates an annual operating cost ratio of 2 favoring the two land disposal options as compared to alternate treatment process 15100. This ratio would be even greater (~6) if the sanitary landfill is operated by an outside contractor. The total annual energy requirement for process 15100 is approximately fourfold greater than that required for the two land disposal options.

7.1.10 Elemental Phosphorus Manufacturing Plants - Waste Streams 16A and 16B

The two waste streams 16A and 16B are generated at the same plant site. Therefore, in Table 81 the costs incurred by the two treatment processes 16A100 and 16B100 are combined for purposes of comparison to the land disposal options. Evaluation of this table indicates annual operating cost ratios of 1.4 to 5 favoring the land disposal options. However, since annual operating cost contribution of treatment system (16B100 is only a small fraction of the total combined cost of the two systems 16A100 and

16B100) it was deemed necessary to study this latter stream separately. Table 82 presents alternative treatment costs for the phossy water stream (stream 16B) alone. As shown, the net annual operating cost per metric ton of product for this treatment system is significantly lower than the costs estimated for the two land disposal options (ratios of 5 to 15 favoring treatment system 16B100). This is due to the credit given for the recovered phosphorus which is a high value commodity.

In both cases, the total energy requirements for the treatment processes are appreciably greater than for the respective land disposal options.

7.1.11 Phosphorus Trichloride Manufacturing Plants - Waste Stream 18

Table 83 indicates an annual operating cost ratio of 5 favoring the land disposal options when they are compared to the alternate treatment process 18100. This ratio would be even greater (~50) if the sanitary landfill is operated by an outside contractor. The total annual energy requirement is negligible both for process 18100 and for the two land disposal options.

TABLE 71

COMPARISON OF TREATMENT COSTS FOR WASTE GENERATED AT A MERCURY CELL CHLOR-ALKALI PLANT

Waste: Mercury bearing brine purification sludge and wastewater treatment sludge

Typical Plant Size: 250 kkg/day of chlorine

	Treatment/Disposal Alternatives				
Treatment System No.	01100	01200A	01200B	Sanitary Landfill	Chemical Landfill
Capital Investment, $MM	1.54	0.725	0.600	0.171	0.707
Annual Operating Costs ($):					
Annual O&M (excluding power and energy)	720,100	181,000	176,000	81,970	120,015
Annual Energy Cost	—	39,200	39,200	15,730[1]	15,730[1]
Annual Power Cost	39,000	27,000	27,000	—	—
Total Annual Operating Cost	759,100	395,200	363,160	118,890	242,135
By-product credit	(132,800)	(132,800)	(132,800)	—	—
Net Annual Operating Cost[3]	626,300	262,400	230,360	118,890	242,135
Annual Energy Requirement, MM kgcal	—	4,939	4,939	10,082[2]	10,082[2]
Annual Power Requirement, kwh	1,300,000	900,000	900,000	—	—
Unit Cost:					
$/kkg of product	6.9	2.9	2.5	1.30	2.65
$/kkg of raw waste (dry basis)	361	152	134	70	140
$/kkg of raw waste (wet basis)	89	37	32	17	34

Description of Treatments:

01100	Sodium Hypochlorite dissolution of mercury in sludge
01200A	Sludge calcination using multiple hearth roaster
01200B	Sludge calcination using fluidized bed roaster

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[1] Utilities (heat, light and water) for a personnel building on the landfill site have been omitted from consideration. The individual amounts involved for these items are unknown but considered negligible.

[2] Based on heat value of 9,321 kg cal/1 (140,000 BTU/gal) for diesel fuel. This value is used in all the tables in this section.

[3] Includes variable and fixed costs.

TABLE 72

COMPARISON OF TREATMENT COSTS FOR WASTE GENERATED AT A DIAPHRAGM CELL CHLOR-ALKALI PLANT

Waste: Lead bearing sludge and asbestos separator waste

Typical Plant Size: 450 kkg/day of chlorine

	Treatment/Disposal Alternatives		
Treatment System No.	04100 and 05100[1]	Sanitary Landfill	Chemical Landfill
Capital Investment, $MM	0.515	0.134	0.268
Annual Operating Costs ($):			
Annual O&M (excluding power and energy)	217,200	79,880	90,330
Annual Energy Cost	3,900	10,010	10,010
Annual Power Cost	18,900	—	—
Total Annual Operating Cost	346,300	108,650	139,800
By-product credit	(10,725)	—	—
Net Annual Operating Cost[2]	335,575	108,650	139,800
Annual Energy Requirement, MM kg cal	490	495	495
Annual Power Requirement, kwh	585,000	—	—
Unit Cost:			
$/kkg of product	2.0	0.66	0.85
$/kkg of raw waste (dry basis)	545	178	229
$/kkg of raw waste (wet basis)	144	47	60

Description of Treatments:

04100	Detoxification of asbestos by fusion
05100	Recovery of impure metallic lead by smelting

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[1] These two treatment processes are considered together for purposes of comparison with sanitary and chemical landfills even though 04100 and 05100 could operate as separate alternative treatment processes.

[2] Includes variable and fixed costs.

TABLE 73

COMPARISON OF TREATMENT COSTS FOR WASTE GENERATED AT A DOWNS CELL METALLIC SODIUM PLANT

Waste: Metallic sodium-calcium waste

Typical Plant Size: 140 kkg/day of metallic sodium

	Treatment/Disposal Alternatives			
		Sanitary Landfill		
Treatment System No.	06100	Company Operated	Contractor Operated	Chemical Landfill
Capital Investment, $MM	1.409	0.103	0.010	0.152
Annual Operating Costs ($):				
Annual O&M (excluding power and energy)	1,974,500	32,220	27,220	43,080
Annual Energy Cost	1,300	594	—	594
Annual Power Cost	331,000	—	—	—
Total Annual Operating Cost	2,591,800	47,990	27,220	66,460
Recovered product credit	(329,200)	—	—	—
Net Annual Operating Cost[1]	2,262,600	47,990	27,220	66,460
Annual Energy Requirement, MM kg cal	170	38	—	38
Annual Power Requirement, kwh	11,000,000	—	—	—
Unit Cost:				
$/kkg of product	44	0.94	0.53	1.30
$/kkg of raw waste	3,170	72	41	100

Description of Treatment:

06100 Electrolysis and melting of sodium-calcium waste in degrader cells for sodium and cell bath (calcium chloride/sodium chloride mixture) recovery

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[1] Includes variable and fixed costs.

TABLE 74

COMPARISON OF TREATMENT COSTS FOR WASTE GENERATED AT A CHLORIDE PROCESS TITANIUM DIOXIDE PLANT

Waste: Chromium hydroxide bearing heavy metal sludge from wastewater treatment

Typical Plant Size: 100 kkg/day of titanium dioxide

	Treatment/Disposal Alternatives		
Treatment System No.	07100	Sanitary Landfill	Chemical Landfill
Capital Investment, $MM	13.257	3.150	14.020
Annual Operating Costs ($):			
Annual O&M (excluding power and energy)	1,134,300	685,830	1,535,990
Annual Energy Cost	3,127,000	188,710	188,710
Annual Power Cost	98,000	—	—
Total Annual Operating Cost[1]	7,046,500	1,068,360	3,608,050
Annual Energy Requirement, MM kgcal	393,880	12,100	12,100
Annual Power Requirement, kwh	3,270,000	—	—
Unit Cost:			
$/kkg of product	193	29	99
$/kkg of raw waste (dry basis)	138	21	71
$/kkg of raw waste (wet basis)	6.89	1.05	2.55

Description of Treatment:

07100 Calcination of dewatered sludge to convert hazardous material to insoluble oxide

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[1] Includes variable and fixed costs

TABLE 75

COMPARISON OF TREATMENT COSTS FOR WASTE GENERATED AT A CHROME COLOR AND INORGANIC PIGMENT MANUFACTURING PLANT

Waste: Heavy metal bearing wastewater treatment sludge

Typical Plant Size: 23 kkg/day chrome colors and inorganic pigments

	Treatment/Disposal Alternatives			
Treatment System No.	08100	08200	Sanitary Landfill	Chemical Landfill
Capital Investment, $MM	1.066	0.195	0.117	0.159
Annual Operating Costs ($):				
Annual O&M (excluding power and energy)	141,750	135,825	79,200	82,430
Annual Energy Cost	12,500	7,200	10,010	10,010
Annual Power Cost	4,500	1,200	—	—
Total Annual Operating Cost[1]	374,750	183,825	107,980	117,600
Annual Energy Requirement, MM kgcal	1,580	460	640	660
Annual Power Requirement kwh	150,000	39,000	—	—
Unit Cost:				
$/kkg of product	45	22	13	14
$/kkg of raw waste (dry basis)	450	220	129	140
$/kkg of raw waste (wet basis)	342	167	99	107

Description of Treatments:

08100	Detoxification of heavy metal hydroxides by calcination
08200	Detoxification of heavy metal hydroxides by evaporation and asphalting

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[1] Includes variable and fixed costs

TABLE 76

COMPARISON OF TREATMENT COSTS FOR WASTE GENERATED AT A HYDROFLUORIC ACID MANUFACTURING PLANT

Waste: Calcium fluoride bearing gypsum sludge

Typical Plant Size: 64 kkg/day of hydrofluoric acid

	Treatment/Disposal Alternatives		
Treatment System No.	09100	Sanitary Landfill	Chemical Landfill
Capital Investment, $MM	2.691	1.401	5.854
Annual Operating Costs ($):			
Annual O&M (excluding power and energy)	7,050,100	371,010	718,340
Annual Energy Cost	800,000	106,400	106,400
Annual Power Cost	27,000	—	—
Total Annual Operating Cost[1]	8,422,600	557,000	1,592,700
Annual Energy Requirement, MM kgcal	50,400	6,830	6,830
Annual Power Requirement, kwh	900,000	—	—
Unit Cost:			
$/kkg of product	360	24	68
$/kkg of raw waste (dry basis)	96	6.36	18
$/kkg of raw waste (wet basis)	77	5.09	15

Description of Treatment:

09100	Detoxification of calcium fluoride bearing gypsum sludge by evaporation and asphalting

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[1] Include variable and fixed costs

TABLE 77

COMPARISON OF TREATMENT COSTS FOR WASTE GENERATED AT AN ALUMINUM FLUORIDE MANUFACTURING PLANT

Waste: Calcium fluoride bearing wastewater treatment sludge
Typical Plant Size: 145 kkg/day of aluminum fluoride

	Treatment/Disposal Alternatives		
Treatment System No.	11100	Sanitary Landfill	Chemical Landfill
Capital Investment, $MM	0.261	0.282	0.795
Annual Operating Costs ($):			
Annual O&M (excluding power and energy)	756,850	102,740	142,830
Annual Energy Cost	80,000	21,450	21,450
Annual Power Cost	3,600	—	—
Total Annual Operating Cost[1]	893,250	154,820	274,450
Annual Energy Requirement, MM kgcal	5,040	1,385	1,385
Annual Power Requirement, kwh	120,000	—	—
Unit Cost:			
$/kkg of product	17	2.93	5.19
$/kkg of raw waste (dry basis)	94	16	29
$/kkg of raw waste (wet basis)	74	13	23

Description of Treatment:
11100 Detoxification of calcium fluoride bearing wastewater treatment sludge by evaporation and asphalting

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[1] Includes variable and fixed costs

TABLE 78

COMPARISON OF TREATMENT COSTS FOR WASTE GENERATED AT A SODIUM SILICOFLUORIDE MANUFACTURING PLANT

Waste: Calcium fluoride bearing wastewater treatment sludge

Typical Plant Size: 45 kkg/day of sodium silicofluoride

	Treatment/Disposal Alternatives		
Treatment System No.	13100	Sanitary Landfill	Chemical Landfill
Capital Investment, $MM	0.383	0.228	0.691
Annual Operating Costs ($):			
Annual O&M (excluding power and energy)	489,250	132,780	168,900
Annual Energy Cost	60,000	30,110	30,110
Annual Power Cost	15,300	—	—
Total Annual Operating Cost[1]	553,450	186,040	293,740
Annual Energy Requirement, MM kcal	3,780	1,930	1,930
Annual Power Requirement, kwh	140,000	—	—
Unit Cost:			
$/kkg of product	38	11	18
$/kkg of raw waste (dry basis)	247	73	115
$/kkg of raw waste (wet basis)	75	22	35

Description of Treatment:

13100 Detoxification of calcium fluoride bearing wastewater treatment sludge by evaporation and asphalting

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[1] Includes variable and fixed costs

TABLE 79

COMPARISON OF TREATMENT COSTS FOR WASTE GENERATED AT A CHROMATES MANUFACTURING PLANT

Waste: Chromium bearing wastewater treatment sludge and ore residue

Typical Plant Size: 182 kkg/day of chromates

	Treatment/Disposal Alternatives		
Treatment System No.	14100	Sanitary Landfill	Chemical Landfill
Capital Investment, $MM	4.914	1.010	3.688
Annual Operating Costs ($):			
Annual O&M (excluding power and energy)	2,395,800	255,320	464,200
Annual Energy Cost	490,000	72,900	72,900
Annual Power Cost	29,400	---	---
Total Annual Operating Cost[1]	3,911,300	511,720	1,027,050
Annual Energy Requirement, MM kgcal	61,760	4,680	4,680
Annual Power Requirement, kwh	980,000	---	---
Unit Cost:			
$/kkg of product	59	7.70	15
$/kkg of raw waste (dry basis)	72	9.35	19
$/kkg of raw waste (wet basis)	54	7.01	14

Description of Treatment:

14100	Detoxification of chromium bearing wastewater treatment sludge and ore residue by calcination

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[1] Includes variable and fixed costs

TABLE 30

COMPARISON OF TREATMENT COSTS FOR WASTE GENERATED AT A NICKEL SULFATE MANUFACTURING PLANT

Waste: Nickel bearing wastewater treatment sludges

Typical Plant Size: 9 kkg/day of nickel sulfate

	Treatment/Disposal Alternatives			
		Sanitary Landfill		
Treatment System No.	15100	Company Operated	Contractor Operated	Chemical Landfill
Capital Investment, $MM	0.099	0.086	0.005	0.118
Annual Operating Costs ($):				
Annual O&M (excluding power and energy)	48,450	21,420	14,880	23,920
Annual Energy Cost	—	1,056	—	1,056
Annual Power Cost	9,600	—	—	—
Total Annual Operating Cost[1]	78,150	35,740	14,880	43,220
Annual Energy Requirement, MM kgcal	—	68	—	68
Annual Power Requirement, kwh	320,000	—	—	—
Unit Cost:				
$/kkg of product	25	11	4.53	13
$/kkg of raw product (dry basis)	424	196	81	237
$/kkg of product (wet basis)	212	98	41	118

Description of Treatment:

15100 Recovery of nickel from wastewater treatment sludge by use of high gradient magnetic separation

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[1] Includes variable and fixed costs

TABLE 81

COMPARISON OF TREATMENT COSTS FOR WASTE GENERATED AT AN ELEMENTAL PHOSPHORUS MANUFACTURING PLANT[1]

Waste: Calcium fluoride bearing wastewater treatment sludge and phossy water

Typical Plant Size: 136 kkg/day of elemental phosphorus

	Treatment/Disposal Alternatives		
Treatment System No.	16A100[1] and 16B100	Sanitary Landfill	Chemical Landfill
Capital Investment, $MM	1.421	0.635	4.993
Annual Operating Costs ($):			
Annual O&M (excluding power and energy)	2,600,950	482,100	1,280,000
Annual Energy Cost	294,600	50,050	50,050
Annual Power Cost	11,500	—	—
Total Annual Operating Cost	3,192,250	570,000	2,061,250
Product Recovery Credit	(321,000)	—	—
Net Annual Operating Cost[2]	2,874,050	570,000	2,061,250
Annual Energy Requirement, MM kgcal	19,480	3,210	3,210
Annual Power Requirement, kwh	382,000	—	—
Unit Cost:			
$/kkg of product	57	11	42
$/kkg of raw waste (dry basis)	145	30	108
$/kkg of raw waste (wet basis)	77	15	55

Description of Treatments:

16B100	Recovery of phosphorus from phossy water by heat treatment and distillation
16A100	Detoxification of calcium fluoride bearing wastewater sludge by evaporation and asphalting

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[1] These two treatment processes are considered together for purposes of comparison with sanitary and chemical landfills, even though 16A100 and 16B100 would operate as separate treatment processes.

[2] Includes variable and fixed costs

TABLE 82

COMPARISON OF TREATMENT COSTS FOR WASTE GENERATED AT AN ELEMENTAL PHOSPHORUS MANUFACTURING PLANT

Waste: Phossy Water

Typical Plant Size: 136 kkg/day of elemental phosphorus

	Treatment/Disposal Alternatives		
Treatment System No.	**16B100**	**Sanitary Landfill**	**Chemical Landfill**
Capital Investment, $MM	0.544	0.208	1.702
Annual Operating Costs ($):			
Annual O&M (excluding power and energy)	270,500	374,560	926,180
Annual Energy Cost	14,600	12,870	12,870
Annual Power Cost	5,900	—	—
Total Annual Operating Cost	401,400	400,040	1,189,400
Product Recovery Credit	(321,000)	—	—
Net Annual Operating Cost [1]	80,400	400,040	1,189,400
Annual Energy Requirement, MM kgcal	1,845	827	827
Annual Power Requirement, kwh	196,000	—	—
Unit Cost:			
$/kkg of product	1.6	8.06	24
$/kkg of raw waste (dry basis)	120	609	1,810
$/kkg of raw waste (wet basis)	12	60	178

Description of Treatment:

16B100 Recovery of phosphorus from phossy water by heat treatment and distillation

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[1] Includes variable and fixed costs

TABLE 83

COMPARISON OF TREATMENT COSTS FOR WASTE GENERATED AT A PHOSPHORUS TRICHLORIDE MANUFACTURING PLANT

Waste: Still bottoms from phosphorus trichloride distillation

Typical Plant Size: 58,000 kkg/yr of phosphorus trichloride

	Treatment/Disposal Alternatives			
		Sanitary Landfill		
Treatment System No.	18100	Company Operated	Contractor Operated	Chemical Landfill
Capital Investment, $MM	0.046	0.071	0.001	0.078
Annual Operating Costs ($):				
Annual O&M (excluding power and energy)	95,340	9,340	2,110	9,860
Annual Energy Cost	—	260	—	260
Annual Power Cost	—	—	—	—
Total Annual Operating Cost[1]	104,540	21,130	2,110	22,700
Annual Energy Requirement, MM kgcal	—	17	—	17
Annual Power Requirement, kwh	—	—	—	—
Unit Cost:				
$/kkg of product	1.8	0.36	0.04	0.39
$/kkg of raw waste	1,740	362	36	389

Description of Treatment:

18100 Distillation of phosphorus trichloride still bottoms for recovery of impure arsenic trichloride

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[1] Includes variable and fixed costs

TABLE 84

COMPARISON STUDIES - ANNUAL OPERATING COSTS AND ENERGY REQUIREMENTS

			Comparison of Treatment Process to Sanitary Landfill		Comparison of Treatment Process to Chemical Landfill	
Industry	Waste Stream	Treatment System	Ratio of Annual Operating Costs	Ratio of Total Annual Energy Requirements	Ratio of Annual Operating Costs	Ratio of Total Annual Energy Requirements
Chlor-Alkali Plants						
a. Mercury cell operations	1 & 2	01100	5.3	1.1	2.5	1.1
	1 & 2	01200	2.1	6	1.0	6
b. Diaphragm cell operations	4 & 5	04100 & 05100 combined	3.0	2	2.4	2
Sodium Plants	6	06100	47.1 (83)[1]	260	34.0	260
Titanium Dioxide Chloride Process Plants	7	07100	6.6	33	2.0	33
Chrome Pigment Plants	8	08100	3.5	2.6	3.2	2.6
		08200	1.3	0.8	1.2	0.8
Hydrofluoric Acid Plants	9	09100	14.8	7.5	5.2	7.5
Aluminum Fluoride Plants	11	11100	5.8	3.7	3.3	3.7
Sodium Silicofluoride Plants	13	13100	3.0	2	1.9	2
Chromates Plants	14	14100	7.8	13	3.9	13
Nickel Sulfate Plants	15	15100	2.4 (6)[1]	4.1	2.0	4.1
Phosphorus Plants	16A&16B	16A100&16B100 combined	5.0	6.2	1.4	6.2
	16B alone	16B100	0.2	2.4	0.07	2.4
Phosphorus Trichloride Plants	18	18100	5 (50)[1]	~0	4.7	~0

Note:[1] Numbers in parentheses assume the sanitary landfill operation by an outside contractor.

7.2 Effect of Treatment Cost on Product Price

Table 85 presents the anticipated economic impact which the various manufacturers would incur from the implementation of any of these various treatment systems. Since, as a rule, the costs of treatment are recovered by producing establishments, the value per metric ton of product produced would be increased. With the exception of one calcination (07100) and three evaporation and asphalting (09100, 13100 and 16A100) systems which are highly energy intensive and require large capital outlays, the incremental increase on product price would be under 10%. In eleven of the sixteen treatment systems, the incremental increase would be under 5%. In one treatment system, where the incremental increase is of the order of 40% (09100), it is highly questionable if the method of treatment would be practical. This system would consume enormous quantities of asphalt and would have the added problem of the continued need for new landfills if this product is proven to be unsuitable for use as aggregate.

7.3 Effect of Land Disposal Cost on Product Price

Table 86 presents the anticipated economic impact which the various manufacturers would incur from the implementation of either company-owned sanitary or chemical landfill disposal options. It is expected that the cost of developing and operating these landfills would be recovered by the producing establishments, increasing the value per metric ton of product produced. In the case of sanitary landfill operations, the incremental increase on product price is quite small in every case (under 2%), except for waste streams 7B and 9 (under 3%) and waste stream 13 (under 6%). In the case of chemical landfill operations, 10 of the 18 waste streams (or stream combinations), show an incremental increase on product price under 2%, two waste streams show less than a 4% increase, and three waste streams show between an 8 to 10% increase.

7.4 Product Recovery Economics

Six of the sixteen alternate treatment processes are resource recovery as well as detoxification systems. Three of these processes recover product or raw material while four accomplish by-product recovery (one process recovers both product and by-product).* Table 87 presents the break-even cost point (in $/kg) for each of the respective recovered materials. Table 88 compares the break-even points to the current and to the five-year selling price projections of the subject commodities. Figure 36 was used to extrapolate the commodity selling prices to the year 1981. Prices for these commodities, 1971 through 1976, were obtained from the Chemical Marketing Reporter.

Tables 87 and 88 indicate that only phosphorus recovery from phossy water would be a practicable resource recovery process both at the current selling price and the anticipated 1981 price. The other

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* By-product in this sense is a material, not necessarily resulting from the chemical reaction by which the product is made, but recoverable from waste generated in the process.

TABLE 85

EFFECT OF TREATMENT COST ON PRODUCT PRICE

Product	Waste Treatment System	Treatment Cost, \$/kkg Product	Product Price 1976, \$/kkg[1]	Per Cent of Product Price
Chlorine	01100	6.9	165	4.2
Chlorine	01200	2.7[2]	165	1.6
Chlorine	04100	1.2	165	0.7
Chlorine	05100	0.8	165	0.5
Sodium	06100	44	638	6.9
Titanium dioxide	07100	193	1,055	18.3
Chrome pigments	08100	45	2,045	2.2
Chrome pigments	08200	22	2,045	1.1
Hydrofluoric acid	09100	360	902	40.0
Aluminum fluoride	11100	17	385	4.4
Sodium silicofluoride	13100	38	220	17.3
Chromates	14100	59	637	9.3
Nickel Sulfate	15100	25	1,670	1.5
Phosphorus	16A100	56	1,340	4.2
Phosphorus	16B100	1.6	1,340	0.1
Phosphorus trichloride	18100	1.8	815	0.2

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[1] Source: Chemical Marketing Reporter 1976. Where price was given as a range, the high value was used.

[2] Average of systems 01200A and 01200B (multiple hearth vs. fluidized bed calciner).

TABLE 86

Effect of Land Disposal Option Cost on Product Price

Product	Product Price[1] 1976, $/kkg	Waste Stream Number	Sanitary Landfill Option: Cost, $/kkg of Product	Sanitary Landfill Option: Percent of Product Price	Chemical Landfill Option: Cost, $/kkg of Product	Chemical Landfill Option: Percent of Product Price
Chlorine	165	1 & 2	1.30	0.8	2.65	1.6
Chlorine	165	3, 4 & 5	0.68	0.4	0.91	0.6
Chlorine	165	4 & 5	0.66	0.4	0.85	0.5
Sodium	638	6[2]	0.53[3]	0.08	1.30	0.2
Titanium Dioxide	1,054	7B	29.27	2.8	98.85	9.4
Chrome Pigments	2,045	8	12.86	0.6	14.01	0.7
Hydrofluoric Acid	902	9	23.84	2.7	68.18	7.6
Aluminum Fluoride	385	11	2.93	0.8	5.19	1.3
Sodium Silicofluoride	220	13	11.33	5.2	17.88	8.1
Chromates	637	14	7.70	1.2	15.46	2.4
Nickel Sulfate	1,670	15	4.53[3]	0.3	13.15	0.8
Phosphorus	1,340	16A & 16B	11.48	0.9	41.52	3.1
Phosphorus	1,340	16B	8.06	0.6	23.96	1.8
Phosphorus Pentasulfide	770	17	0.09[3]	0.01	0.47	0.06
Phosphorus Trichloride	815	18	0.04[3]	0.005	0.39	0.05

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[1] Source: Chemical Marketing Reporter, 1976. Where price is given as a range, the high value was used.

[2] Landfilling of this waste is highly conceptual since this waste is extremely flammable and explosive should it be contacted by moisture.

[3] This cost is for very small streams where the company-owned sanitary landfill is operated intermittently by an outside contractor. This cost is significantly smaller than if the waste generator were to operate the landfill. The latter cost for the cases involved ranges from 2 to 9 times larger than the outside contractor cost.

TABLE 87

RESOURCE RECOVERY TREATMENT SYSTEMS - RECOVERED MATERIAL CURRENT BREAK-EVEN POINT

Product	Waste Treatment System		Annual Product Recovery, kg/yr	Annual By-Product Recovery, kg/yr	Break Even Point, $/kg	
	System No.	Total Annual Operating Cost, $			Product Recovery	By-Product Recovery
Chlorine	01100	759,100	—	14,600 (mercury)	—	52
Chlorine	01200	379.000[1]	—	14,600 (mercury)	—	26
Chlorine	05100	141,000	—	32,500 (lead)	—	4.4
Sodium	06100	2,591,800	1,046,000	226,000 ($CaCl_2$)	2.48	11
Nickel Sulfate	15100	87,300	850[2]	—	103	—
Phosphorus	16B100	398,900	401,000	—	0.99	—

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[1] Average of systems 01200A and 01200B (multiple hearth or fluidized bed calciner).

[2] As a 31% by weight slurry of nickel hydroxide which would be raw material in the manufacture of nickel sulfate.

TABLE 88

RESOURCE RECOVERY TREATMENT SYSTEMS - COMPARISON OF CURRENT AND FIVE-YEAR PROJECTION RECOVERED COMMODITY PRICE AGAINST BREAK-EVEN POINT

Recovered Material	Waste Treatment System	Break Even Point, \$/kg[1]	
		Current	Five-Year Projection
mercury	01100	52 (9.15)	52 (10.60)
mercury	01200	26 (9.15)	26 (10.60)
lead	05100	4.35 (0.44)	4.35 (0.70)
sodium	06100	2.48 (0.64)	2.48 (0.60)
calcium chloride, anhydrous	06100	11 (0.12)	11 (0.12)
nickel hydroxide	15100	103 (4.42)[2]	103 (6.48)[2]
phosphorus	16B100	0.99 (1.34)	0.99 (1.75)

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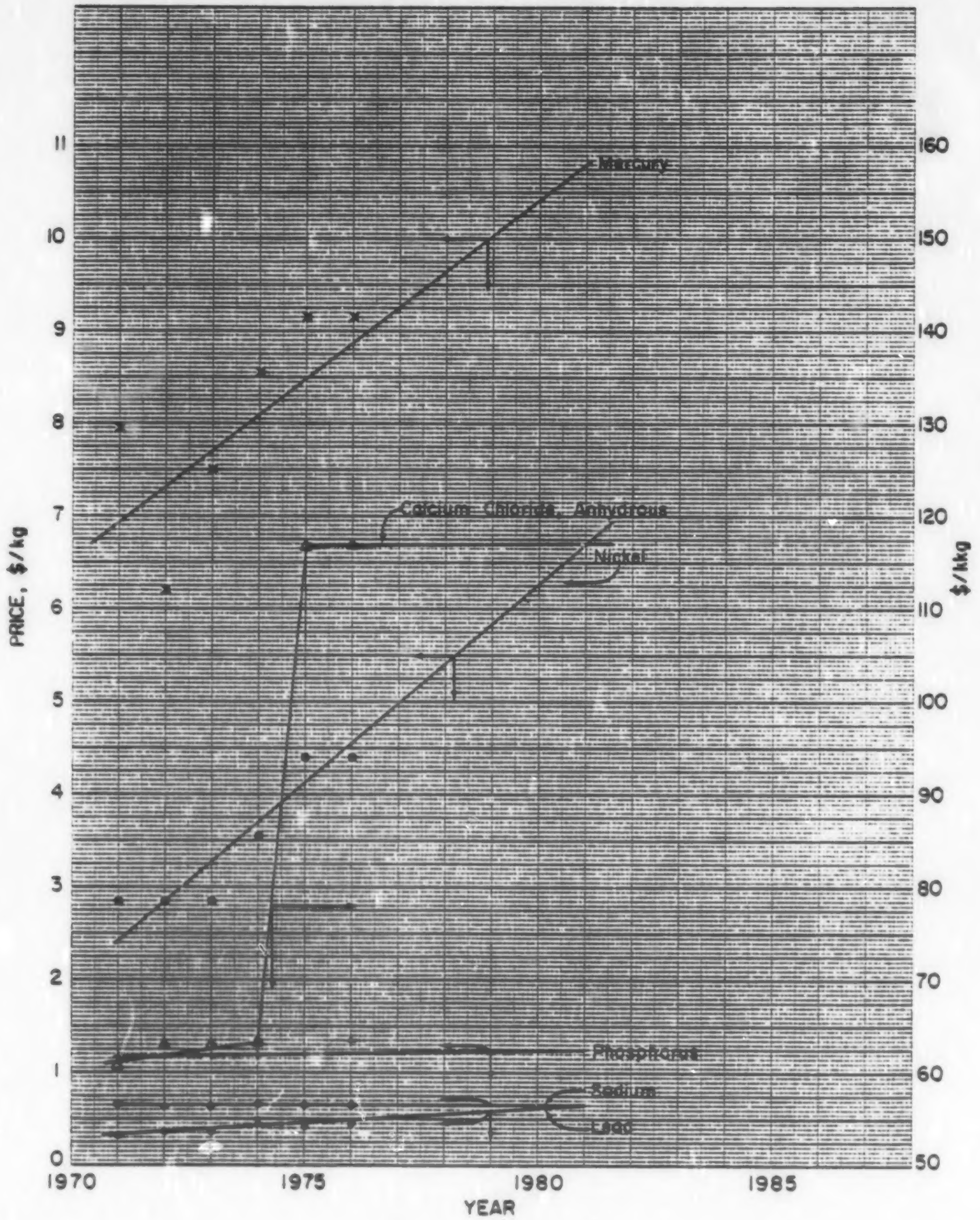
[1] Number in parentheses is commodity selling price.

[2] Number in parentheses is price of nickel metal.

FIGURE 36 EXTRAPOLATED MATERIAL PRICE THROUGH 1981



Source: Date points from Chemical Marketing Reporter (1971-1976) treatment processes may only be justified with potentially hazardous waste detoxification as a prime objective and resource recovery as secondary.

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9.0 GLOSSARY

Air Pollution - The presence in the air of one or more air contaminants in quantities injurious to human, plant or animal life, or property, or which unreasonably interferes with the comfortable enjoyment thereof.

Ash - The solid residue left after incineration in the presence of oxygen.

Brine - An aqueous salt solution.

Calcination - The roasting or burning of any substance to bring about physical or chemical changes; e.g., the conversion of limestone to quicklime.

Caustic - Capable of destroying or eating away by chemical action. Applied to strong bases and characterized by the presence of hydroxyl ions in solution. Usually applied as a name for sodium hydroxide.

Centrifuge - A device having a rotating container in which centrifugal force separates substances of differing densities.

Coke - The carbonaceous residue of the destructive distillation (carbonization) of coal or petroleum.

Condensation - Transformation from a gas to a liquid.

Conditioning - A physical or chemical treatment given to water used in the plant or discharged.

Cooling water - Water which is used to absorb waste heat generated in the process. Cooling water can be either contact or non-contact.

Crystallization - The formation of crystalling substances from solutions or melts.

Cyclone Separator - A mechanical device which removes suspended solids from gas streams.

Dewater - Remove water from solid material by wet classification, centrifugation, filtration, or similar solid-liquid separation techniques.

Digester - A pressure vessel or autoclave used to effect dissolution of raw materials into aqueous solutions.

Dross - The scum formed on the surface of molten metal due to oxidation or the rising of impurities to the surface.

Effluent - The wastewater discharged from a point source to a waterway, other body of water or publicly owned treatment works.

Electrostatic Precipitator - A gas cleaning device using the principle of placing an electrical charge on a solid particle which is then attracted to an oppositely-charged collector plate.

Filtrate - Liquid passing through a filter.

Filtration - Removal of solid particles from liquid or particles from air or gas stream through a permeable membrane.

Flocculation - The combination or aggregation of suspended solid particles in such a way that they form small clumps. The term is used as a synonym for coagulation.

Flotation - A separation method for ore in which a froth created in water by a variety of reagents floats some finely crushed minerals, whereas other minerals sink.

Fluidized Bed Reactor - A reactor in which finely divided solids are caused to behave like fluids due to their suspension in a moving gas or liquid stream.

Fusion - The act of melting or flowing together.

Gas Washer (or wet scrubber) - Apparatus used to remove entrained solids and other substances from a gas stream.

Head - Total feet of fluid (water).

Heavy Metal - One of the metal elements not belonging to the alkali or alkaline earth group. In this study, the classification includes titanium, vanadium, iron, nickel, copper, mercury, lead, cadmium and chromium.

High-Gradient Magnetic Separation (HGMS) - A separation process for removing magnetic and paramagnetic particles from liquid and slurry streams.

Kiln (rotary) - A large cylindrical mechanized type of furnace used for calcination.

Leaching - The process of extraction of a soluble component from a mixture with an insoluble component, by percolation of the mixture with a solvent.

Milling - Mechanical treatment of materials to produce a powder, to change the size or shape of metal powder particles, or to coat one powder mixture with another.

Mother Liquor - The solution from which crystals are formed.

Neutralization - The addition of acid or base to a solution in order to bring the pH to a value of 7.

pH - A measure of the relative acidity or alkalinity of water. A pH value of 7.0 indicates a neutral condition; less than 7 indicates a predominance of acids, and greater than 7, a predominance of alkalies. There is a tenfold increase (or decrease) from one pH unit level to the next, e.g., tenfold increase of alkalinity from pH 8 to pH 9.

Plant Effluent or Discharge After Treatment - The wastewater discharged from the industrial plant. In this definition, any waste treatment device (pond, trickling filter, etc.) is considered part of the industrial plant.

Precipitation - The formation of solid particles in a solution.

Pressure Leaf Filter - A filter containing a series of parallel rectangular plates (called leaves) mounted either vertically or horizontally in a cylindrical pressure tank. They are adapted to wet solids discharge and their widest use is for precoat filtration.

Pretreatment - The necessary processing given materials before they can be properly utilized in a process or treatment facility.

Process Effluent or Discharge - The volume of wastewater emerging from a particular use in the plant.

Process Water - Water which is used in the internal plant streams from which products are ultimately recovered, or water which contacts either the raw materials or product at any time.

Reduction - A chemical change in which the oxidation state (positive valence) of an element is decreased.

Roasting - The oxidation of ores in a current of air in a furnace heated by wood, coal or oil.

Rotary Vacuum Filter - A fixed media filter, which consists of a continuous belt of fabric or wire mesh stretched over a steel cage-like drum which rotates around a central trunnion. A vacuum is applied to the inside of the drum, thus causing the liquid being filtered to be forced through the filter medium, leaving wet solids adhering to the outer surface.

Sedimentation - The falling or settling of solid particles in a liquid, as a sediment.

Settling Pond - A large shallow body of water into which industrial wastewaters are discharged. Suspended solids settle from the wastewaters due to the large retention time of water in the pond.

Sludge - The settled mud from a clarifier thickener. Generally, almost any flocculated, settled mass.

Slurry - A watery suspension of solid materials.

Smelting - The recovery of metals from their ores by a process which includes fusion. In general, it includes (a) calcination and roasting to remove sulfur and other volatile constituents; (b) reduction or smelting during which the metals are fused and separated from gangue; (c) refining, during which the metals are purified.

Solute - A dissolved substance.

Solvent - A liquid used to dissolve materials.

Thickener - A device or system wherein the solid contents of slurries or suspensions are increased by evaporation of part of the liquid phase, or by gravity settling and mechanical separation of the phases.

Total Dissolved Solids (TDS) - The total amount of dissolved solid materials present in an aqueous solution.

Total Suspended Solids (TSS) - Solid particulate matter found in wastewater streams, which, in most cases, can be minimized by filtration or settling ponds.

Vaporization - A change from a liquid to a gaseous state at elevated or normal temperatures.

Waste Discharged - The amount (usually expressed as weight) of some residual substance which is suspended or dissolved in the plant effluent.

Waste Generated (raw waste) - The amount (usually expressed as weight) of some residual substance generated by a plant process or the plant as a whole. This quantity is measured before treatment.

Wet Scrubbing - A gas cleaning system using water or some suitable liquid to entrap particulate matter, fumes, and absorbable gases.

Wiped-film Evaporator - An agitated thin film evaporator which utilizes rotating slotted wiper blades that travel on a thin residue film to maintain a uniform thickness. The slots provide a pumping action to move the film down the heated wall with constant agitation.

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10.0 ACKNOWLEDGMENTS

The preparation of this report was accomplished through the efforts of the staff of General Technologies Division, Versar, Inc., Springfield, Virginia, under the direction of Dr. Robert G. Shaver, Vice President. Mrs. Gayaneh Contos, Senior Chemical Engineer and Principal investigator, directed the project work on the program. Mr. Edwin F. Abrams was the Program Manager.

Mrs. Alexandra G. Tarnay, Project Officer, Environmental Protection Agency, Office of Solid Waste and the staff of Arthur D. Little under the leadership of Dr. Joan B. Berkowitz, through their assistance and advice have made an invaluable contribution to the preparation of this report.

Appreciation is extended to the Manufacturing Chemists Association and The Chlorine Institute for their participation in this program. Appreciation is also extended to the many industrial inorganic chemical producing companies who gave us assistance and cooperation in this program.

Also, our appreciation is extended to the individuals of the technical staff of General Technologies Division of Versar, Inc., for their contribution and assistance during this program. Specifically, our thanks to:

Dr. M. Drabkin, Senior Process Engineer
Ms. C. V. Fong, Environmental Chemist
Ms. N. S. Zimmerman, Environmental Scientist
Mr. R. D. Miller, Draftsman
Mr. M. C. Calhoun, Environmental Scientist

Acknowledgment and appreciation is also given to the secretarial staff of General Technologies Division of Versar, Inc., for their efforts in the typing of drafts, necessary revisions and final preparation of this document.

APPENDIX I

OCCUPATIONAL AND HEALTH EFFECTS OF POTENTIALLY HAZARDOUS COMPOUNDS

1. Arsenic

In all cases of arsenic poisoning it is presumably the ion of arsenious acid, rather than the element itself, which is the toxic principal.[38] The "in vivo" conversion to arsenite explains why all chemical forms of arsenic eventually produce the same toxic syndrome. One exception is gaseous AsH_3 or arsine, which is a potent hemolylic agent, unlike other arsenic derivatives.[38]

Arsenic is notorious for its toxicity to humans. Ingestion of as little as 100 mg usually results in severe poisoning, and as little as 130 mg has proved fatal.[59] Furthermore, arsenic accumulates in the body, so that small doses may become fatal in time. A single dose may require ten days for complete disappearance, and this slow excretion rate is the basis for the cumulative toxic effect. Chronic arsenosis is of slow onset and may not be apparent for 2-6 years. Small eruptions occur on the hands and the soles of the feet sometimes developing into arsenical cancers. Liver and heart ailments may also supervene.[59]

Finely subdivided arsenic compounds, such as arsenic trioxide, are significantly more toxic than coarsely powdered material, since appreciable amounts of the latter may be eliminated in the feces without dissolving. In acute poisoning, symptoms following ingestion relate to irritation of the gastrointestinal tract: nausea, vomiting, diarrhea, which can progress to shock and death.[84] In most cases, the presenting symptoms are those of severe gastritis or gastroenteritis.[38] Because the lesions are due not to local corrosion but to vascular damage from absorbed arsenic, the first symptoms may be delayed several minutes or even a few hours. Eventually a violent hemorrhagic gastroenteritis leads to profound losses of fluid and electrolytes, resulting in collapse, shock and death.[76]

Occasionally, the alimentary symptoms are mild or absent, in which case the presenting complaints are usually referrable to the central nervous system: headache, vertigo, muscle spasm, stupor, delirium and sometimes mania.[38] Urinary excretion of arsenic is markedly enhanced, without damage to the excretory organs, by the administration of BAL (dimercaprol). If prompt, this treatment suppresses most signs and symptoms of acute poisoning.[38]

The water quality standard for arsenic and its compounds is 0.05 mg/l as As (DWS); a more ideal limit would be 0.01 mg/l.[84] The U.S. Occupational Standards for arsenic and its compounds in air is 500 $\mu g/m^3$.[21]

2. Asbestos

Asbestos is toxic by inhalation of dust particles; the tolerance is 5 million particles per cubic foot of air (TLV, ACGIH recommended).

Like other cases of "dust lung" diseases, asbestosis develops slowly.[95] It becomes manifest usually 20-30 years after the first exposure, often long after exposure to asbestos has completely ceased. Unexplained breathlessness on exertion and productive cough often precede the disease by many years.[95]

The essential lesion produced by asbestos dust is a diffuse fibrosis which probably begins as a "collar" about the terminal bronchioles.[76] Usually at least 4-7 years of exposure are required before a serious degree of fibrosis results. There is apparently less predisposition to tuberculosis than is the case with silicosis. Prolonged inhalation can cause cancer of the lungs, pleura and peritoneum.[76]

Exposure to asbestos without development of asbestosis has been shown to increase the risk of lung cancer.[62] Other kinds of dust in addition to asbestos most likely contribute to this development. In asbestos workers who smoke, a 90-fold increase in the incidence of lung cancer over that in non-smokers has been recorded. Some research data strongly suggests a synergism of cigarette smoking and asbestos exposure in the increased risk of lung cancer. It is not known whether this is because of reduced clearance of asbestos, transportation of cigarette smoke carcinogens by asbestos fibers, or the promotion by one factor of cancer initiated by another. Cancer caused by asbestos localizes most often in the lower lobes of the lungs in contrast to the more common site of lung cancer in the upper lobes.[62]

An otherwise rare tumor, called mesothelioma, has been identified with asbestos.[95] Mesotheliomas usually involve the pleura but also originate in the peritoneum. This malignant tumor spreads rapidly over the whole abdominal cavity and into the lymph glands of the body. As in other kinds of lung cancer, the condition starts slowly with chest pain and breathlessness; the patients seldom survive more than a year from the time the diagnosis is established.[95]

All epidemiologic studies that appear to indicate differences in pathogenicity among types of asbestos are flawed by their lack of quantitative data on cumulative exposures, fiber characteristics, and the presence of co-factors.[62] The different types, therefore, cannot be graded as to relative risk with respect to asbestosis. Fiber size is critically important in determining respirability, deposition, retention and clearance from the pulmonary tract and is probably an important determinant of the site and nature of biologic action. Little is known about the movement of the fibers within the human body, including their potential for entry through the gastrointestinal tract. There is evidence though that bundles of fibrils may be broken down within the body to individual fibrils.[62]

3. Carbon Monoxide

Carbon monoxide is a colorless, odorless, toxic gas. Its toxicity results from preferential reaction with hemoglobin. Because of its extremely faint odor and taste, its lethal capacity can be insidious.

Death from inhalation of carbon monoxide is summarized as follows: (1) reduction of the oxygen-carrying capacity of the blood due to the combination with hemoglobin; (2) tissue anoxia especially in the brain, which is very sensitive to lack of oxygen; (3) consequent depression of respiratory center in the brain and decrease in respiration; and (4) failure of heart due to inadequate oxygen supply.

The physiological effects versus carbon monoxide concentration is as follows:

Concentration of Carbon Monoxide, %	Effect
0.01	No symptoms for 2 hours
0.04	No symptoms for 1 hour
0.06 - 0.07	Headache and unpleasant symptoms for 1 hour
0.1 - 0.12	Dangerous for 1 hour
0.35	Fatal in less than 1 hour

As a safe rule, based on sound experiments and experience, concentrations of carbon monoxide above 0.01 percent should not be permitted in houses, garages, laboratories or industrial plants where prolonged exposure to the gas may be experienced.

4. Chlorine Gas

Chlorine gas has a characteristic, pungent odor with a detectability threshold of a few parts per million in air.

Liquid chlorine in contact with eyes, skin, or clothing may cause severe burns; as soon as it is released in the atmosphere, it vaporizes with irritating effects and suffocating action, which were exploited by using it as a war gas. The physiological response to the presence of any amount of chlorine gas in air may be evaluated from the following data published by the Bureau of Mines. Concentration values are given in parts per million by volume.

Least detectable odor, ppm	3.5
Least amount required to cause irritation of throat, ppm	15.1
Least amount required to cause coughing, ppm	30.2
Least amount to cause slight symptoms of poisoning after several hours exposure, ppm	1.0
Maximum amount that can be breathed for one hour without serious effects, ppm	4.0

Amount dangerous in 30 minutes to one hour, ppm	40-60
Amount likely to be fatal after a few deep breaths, ppm	1,000

OSHA regulations for in-plant worker exposure (8-hour time-weighted average) limit emissions of chlorine to less than 1 ppm (less than 3 mg/m^3).

5. Hydrochloric Acid Mist

Hydrochloric acid upon inhalation or ingestion is highly toxic and very corrosive to tissues.

The U.S. Occupational Standard for hydrochloric acid mist in air is 5 ppm.[21]

6. Hydrogen Sulfide

Hydrogen sulfide has been described as an "either-or-poison". This implies that the victims either rapidly succumb to the action of the poison or rapidly recover, if they are removed from the contaminated area. This is, however, an oversimplified picture. Delayed deaths and neurologic sequelae in persons surviving from acute hydrogen sulfide poisoning have been reported. It should be noted that small concentrations of the sulfide compounds are easily detected from the characteristic "rotten-egg" odor. This offensive odor becomes less intense or disappears when the concentration is above 200 ppm. This is probably due to a paralyzing effect of the poison on the olfactory nerve.

Poisonings from hydrogen sulfide are often classified as acute, subacute and chronic. The acute poisonings occur after exposures to high concentrations of the gas and are characterized by a rapid onset of systemic effects, mainly affecting the central nervous system. Concentrations above 250 ppm (350 mg/m^3) may be fatal to human beings. Concentrations of about 500 ppm (700 mg/m^3) may lead to death in less than one hour and 2,000 ppm (2,800 mg/m^3) cause death almost instantaneously. If the exposure to the gas is not excessive, headache, nausea, dizziness, and weakness of the extremities may appear before the victim becomes unconscious. Violent convulsions, probably of anoxic origin, sometimes occur. Death results from respiratory failure, mainly of central origin. Hydrogen sulfide also has an indirect stimulatory effect on respiration (and circulation) mediated through the carotid and aortic chemoreceptors. The initial stimulation of breathing may obviously lead to a more rapid progress of poisoning and makes it difficult for an unprotected person, who enters a contaminated area for rescue purposes, to hold his breath.

Subacute hydrogen sulfide poisonings are characterized by the irritating effects of the gas on the mucous membranes of the eyes and respiratory tract. These effects appear after prolonged exposures to concentrations of 50-200 ppm (70-280 mg/m^3). The action on the eyes is usually predominant and results in an acute conjunctivitis with itching, photophobia, and lacrimation, which may progress to a keratoconjunctivitis with small blisters in the cornea. Persons with chronic inflammation of the eyes should not be employed to work in areas where they are exposed to hydrogen sulfide. The effects on the respiratory tract consist of rhinitis, pharyngitis, bronchitis and pneumonia and, as a sequel to acute poisoning, pulmonary edema.

Chronic hydrogen sulfide poisoning is described as a condition with diffuse symptoms, resulting from prolonged exposure to concentrations which would not cause symptoms of acute or subacute poisoning. The existence of chronic poisoning from the gas is, however, very questionable. Hydrogen sulfide is rapidly detoxified in the mammalian body and is considered to be a non-cumulative poison. The MAC value is 20 ppm or 28 mg/m^3.

Table 89 tabulates the effects of hydrogen sulfide on humans.

There are no current OSHA limits for worker in-plant exposure to hydrogen sulfide.

7. Lead and Lead Salts

Lead is poisonous in all forms. It is one of the most hazardous of the toxic metals because the poison is cumulative and toxic effects are many and severe. Of the various lead compounds, the carbonate, monoxide and sulfate are considered to be more toxic than elemental lead or other lead compounds. The toxicity of lead chromate is less than would be expected, due to its low solubility. All of the lead compounds are sufficiently soluble in digestive juices to be considered toxic.

Lead may enter the human system through inhalation, ingestion or skin contact. Direct skin contact is of negligible importance in connection with inorganic lead compounds. However, in the case of organic lead compounds, skin contact can be a real hazard. Industrially, inhalation of dust, mist or fumes, is the chief method by which lead and its inorganic compounds may enter the body.

The water quality standard for all lead compounds is 0.05 mg/l as lead. The U.S. Occupational Standard for lead in air is 200 μg/m^3.[21]

8. Mercury and its Salts

Airborne mercury may be inhaled directly, may settle out of the atmosphere or fall with rain. It has been demonstrated that man will absorb 75 to 85 percent of inhaled mercury vapor at concentrations of 50 to 350 μg/m^3. Lower concentrations can be absorbed more completely.

The central nervous system is the critical focal point in long-term exposure to mercury vapor. The vapor is absorbed into the blood from the lungs where some of it remains unchanged and some is oxidized to the more damaging mercuric ion. Elemental mercury is lipid-soluble and can diffuse into the central nervous system and similar tissues where most of it is oxidized to mercuric ions. Mercury can accumulate in the brain, testes, and thyroid because its elimination rate from these organs is slow.

TABLE 89

EFFECTS OF HYDROGEN SULFIDE ON HUMANS

Concentration $\mu g/m^3$	Effects
1-45	Odor threshold. No reported injury to health
10	Threshold of reflex effect on eye sensitivity to light
150	Smell slightly perceptible
500	Smell definitely perceptible
15,000	Minimum concentration causing eye irritation
30,000	Maximum allowable occupational exposure for 8 hours (ACGIH Tolerance Limit)
30,000-60,000	Strongly perceptible but no intolerable smell. Minimum concentration causing lung irritation.
150,000	Olfactory fatigue in 2-15 minutes: irritation of eyes and respiratory tract after 1 hour; death in 8 to 48 hrs.
270,000-480,000	No serious damage for 1 hour but intense local irritation; eye irritation in 6 to 8 minutes
640,000-1,120,000	Dangerous concentration after 30 minutes or less
900,000	Fatal in 30 minutes
1,160,000-1,370,000	Rapid unconsciousness, respiration arrest, and death, possibly without odor sensation
1,500,000+	Immediate unconsciousness and rapid death

Mercuric salts are highly toxic to humans and can be readily absorbed through the gastrointestinal tract.

In cases of chronic exposure to mercury vapor, the common symptoms are tremor and psychological disturbances. In addition, loss of appetite, loss of weight and insomnia have been reported.

The OSHA limitations for mercury is 1 mg per 10 cubic meters of air for daily eight-hour time-weighted average exposure. The U.S. Drinking Water Standard for mercury is 0.005 ppm.

9. Nitric Oxides (NO_x)

The health effects of NO_x are not at present a serious problem. Nitric oxide (nitrogen monoxide) is not an irritant and its main toxic potential results from its oxidation to nitrogen dioxide (NO_2). However, NO_2 will attach to hemoglobin and thus in large concentrations could have oxygen-deprivation effects similar to those of carbon monoxide. Nitrogen dioxide is an irritant to eyes and the respiratory tract. Experimentation with animals indicates many pathological changes connected with lung function as well as increased susceptibility to infection. Emphysema has been induced in laboratory animals following long-term exposures to 10 to 25 ppm NO_2. Humans appear to have a threshold of about 0.12 ppm for detection of the chlorine-like odor of NO_2, and therefore high concentrations can be easily detected.

The federal standard for NO_x excluding NO_2 are 0.05 ppm for one year and 0.13 ppm for twenty-four hours exposure time.

The U.S. Occupational Standard for air for nitric oxide and nitrogen dioxide is 225 ppm and 5 ppm, respectively.[21]

10. Phosphorus

Phosphorus poisoning is a potential occupational hazard at the elemental phosphorus production plants. The yellow phosphorus OSHA limit for employee exposure is 0.1 mg/m^3 over an 8-hour time-weighted average.

The acute fatal dose of phosphorus for an adult is between 50 to 100 mg or approximately 1 mg/kg body weight. Recovery, however, has occurred after 0.8 and 1.5 grams. The prognosis for phosphorus poisoning is generally poor, and even in modern times the fatality rate is about 50 percent.

It is especially hazardous to the eyes and can damage them severely. The yellow form of phosphorus when it comes into external contact with the eyes, can cause conjunctivitis with a yellow tint. If the material is inhaled, it can cause photophobia with myosis, dilation of pupils, retinal hemorrhage, congestion of the blood vessels and rarely an optic neuritis. Phosphorus is usually described, for this reason, as a "limiting factor".

Although there are no definite published reports on the kinetics of oxidation of elemental phosphorus in water, it appears that the rate is highly dependent on the degree of dispersion. At concentrations (ca. 10 micrograms/liter) well below the accepted solubility limit of 3 mg/l, with the dissolved oxygen content unspecified, elemental phosphorus disappears by a first order process with a half-life of 2 hours at about 10°C, 0.85 hours at 30°C. At concentrations (50-100 mg/l) well above the solubility limit, with a dissolved oxygen content of 6 to 7 mg/l, the same reaction has a half-life of 80 hours at 30°C and 240 hours at 0°C. The relatively small temperature effect combined with the large inverse concentration effect is consistent with a diffusion controlled process. The oxidation of colloidal phosphorus in seawater is reported to be measurably slower than in fresh water, suggesting that the high salt content brings about agglomeration of the phosphorus particles. Thus, rapidly moving fresh water should lose elemental phosphorus faster than quiescent seawater.

The standard for phosphorus in water and soil is 0.005 mg/l as P, while the provisional limit for phosphorus pentasulfide in soil or water is 0.05 mg/l as P. The U.S. Occupational Standard for air is 100 $\mu g/m^3$.[21]

APPENDIX II

COST BASES FOR COST ANALYSES TASKS

Interest Costs and Equity Financing Charges

Capital investments involve the expenditure of money which must be financed either on borrowed money or from internal equity. Estimates for this study have been based on 10 percent cost of capital, representing a composite number for interest paid or return on investment require. This value and the other costs defined in this section were provided by EPA for purposes of standardization and appear in Table 90.

Time Index for Costs

All cost estimates are based on mid-1976 prices and, when necessary, have been adjusted to this basis using the Chemical Engineering or the Marshall and Stevens Cost Indices.

Useful Service Life

The useful service life of process, treatment and disposal equipment varies depending on the nature of the equipment and process involved, its usage pattern, maintenance care and numerous other factors. Individual companies have their own service life values based on actual experience and use these internal values for amortization. Another source of service life information, less relevant than company experience, is the Internal Revenue Service guidelines. EPA requested that a useful service life of 10 years be used for all equipment in this study.

Depreciation

As treatment and disposal equipment and facilities are used, their economic value decreases or depreciates. At the end of their useful life, it is usually assumed that the salvage or recovery value becomes zero. IRS tax allowances, or depreciation charges, provide capital cost recovery based on either service life or accelerated write-off schedules. In effect, the straight line depreciation approach used herein is similar to a conservative depreciation approach which some companies might actually use for income tax purposes. Using a different depreciation rate would have the impact of changing the cash flow that companies would actually experience based on reported expenses.

Capital Costs

Capital costs are defined for the purposes of this report as all front-end loaded, out-of-pocket expenditures for the provision of treatment/disposal facilities. These costs include any money for research and development necessary to establish the process, land costs when applicable, equipment, construction and installation, buildings, services, engineering, special start-up costs and contractor profits.

TABLE 90

EPA SUPPLIED COST ITEMS

		Consensus
1.	Land Cost, \$/Acre	5,000
2.	Taxes and Insurance, (%)[1]	4
3.	Maintenance, (%)[1]	4
4.	Direct Labor, \$/hr	9.00
5.	Supervision and Administrative, (%)[2]	50
6.	Utility Water, \$/1,000 gal	0.30
7.	Boiler Feed Water, \$/1,000 gal	0.50
8.	Instrument Air, \$/MSCF	20.00
9.	Nitrogen, \$/MSCF	Oct. 4 - figures
10.	Steam, \$/10^6BTU or \$/1,000 lb	4.00
11.	Fuel, \$/10^6BTU	2.00
12.	Electric Power, \$/kwh	0.03
13.	Contingency, (%)	20
14.	Interest Rate on Capital (%)	10
15.	Salvage Value, (%)[3]	none
16.	Amortization Method (Years @ %)	10 years, straight line, @10%
17.	Royalties and Fees	none

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[1] % of Capital

[2] % of Direct Labor

[3] % of Initial Capital

When capital costs are known for a specific plant using a given treatment/disposal technology, cost adjustment to the typical plant size was made using an exponential factor of 0.6.

Contingencies

A contingency figure of 20 percent is added to installed capital cost on all estimates prepared for conceptual systems. This allows for inclusion of added features found necessary after initial design.

Annualized Capital Costs

Almost all capital costs for treatment and disposal facilities are front-end loaded, i.e., most, if not all, of the money is spent during the first year or two of the useful life. This present worth sum can be converted to equipment uniform annual disbursements by utilizing the Capital Recovery Factor Method:

$$\text{Uniform Annual Disbursement} = \frac{P\,i(1+i)^N}{(1+i)^N - 1}$$

where

P = present value (capital expenditure)
i = interest rate, %/100
N = useful life in years

The capital recovery factor method is used for all annualized capital costs on this report. All annual capital recovery costs were calculated based upon a ten-year lifetime and a 10 percent interest rate. The capital recovery factor is then,

$$\frac{i\,(1+i)^N}{(1+i)^N - 1} = \frac{(0.1)(1.1)^{10}}{(1.1)^{10} - 1} = 0.1627$$

Operating Expenses

Annual costs of operating a treatment facility include labor, supervision, maintenance costs, taxes and insurance, power and energy costs, utility, water, steam and chemical costs.

a. Labor and Supervision Costs

The following costs were used for labor and supervisory needs.

Labor Category	$/hour
Direct Labor	9
Supervision and Administrative	50% of direct labor cost

b. Maintenance Cost

Maintenance is taken as 4 percent of invested capital.

c. Taxes and Insurance Costs

Taxes and insurance are taken as 4 percent of invested capital.

d. Power, Energy and Utilities Costs

Costs for power, energy and utilities used in this study are listed below:

Electric power, ¢/kwh	3
Fuel, $\$/10^6$ kg cal ($\$/10^6$ BTU)	7.94 (2.00)
Steam, $\$/10^6$ kg cal ($\$/10^6$ BTU)	15.87 (4.00)
Water, ¢/1,000 liters (¢/1,000 gal)	7.9 (30)

e. Chemical Costs

Chemical costs are variable for each individual case. The source of information used in this study is the Chemical Marketing Reporter, September 27, 1976.

f. Monitoring and Analyses Costs

Actual plant supplied monitoring and analyses costs were available for only two processes,01100 and 06100, both previously demonstrated. These costs for the remaining processes were estimated using judgment as to the individual process requirements relative to the two plants' supplied requirements. It should be noted that monitoring and analyses costs are highly variable and dependent on such factors as frequency of monitoring required, number of streams to be monitored and the number and types of parameters to be measured. The estimated monitoring and analyses costs presented herein are felt to be in the right order of magnitude but may vary as much as a factor of 5 depending on local requirements.

Rationale for "Typical Plants"

All plant costs are estimated for "typical plants" rather than for any actual plant. "Typical plants" are defined for purpose of these cost estimates as:

> the arithmetic average of production size and age for all plants, or the size and age agreed upon by a substantial fraction of the manufacturers in the subcategory producing the given chemical.

It should be noted here that the costs to treat and dispose of hazardous wastes at a given facility may be considerably higher or lower than the typical plant depending on the individual circumstances and the geographical location of the plant.

APPENDIX III

SAMPLE CALCULATION OF COSTS FOR THE SANITARY AND CHEMICAL LANDFILLS

COMPANY OWNED AND OPERATED SANITARY LANDFILL - WASTE STREAMS 1 AND 2

Assumptions and Design Bases for Capital Cost Calculations

Bulk Density, Stream 1: 75 lb/cu ft (after thickening)*
Bulk Density, Stream 2: 90 lb/cu ft
Ratio Sludge/Cover Material: 3
Total Landfill Depth: 20 ft
Landfill Utilization Depth: 15 ft
Years of Landfill Operation: 20
Days of Landfill Operation: 260/yr
Ratio of Total Area Requirement to Usable Landfill Area: 1.5
Land Cost: $5,000/acre
Site Preparation Cost: $0.25/sq yd or $1,210/acre
Total Waste Stream (dry basis): 1 & 2 = 4.75 kkg/day
Total Waste Stream (wet basis): 1 & 2 = 19.5 kkg/day
Total Waste Stream (wet basis, after thickening): 1 & 2 = 12 kkg/day

Land Requirements

Stream 1:

$$\text{Acres/yr} = \frac{11\ \text{kkg}}{\text{day}} \times \frac{1\ \text{ton}}{0.91\ \text{kkg}} \times \frac{2{,}000\ \text{lb}}{\text{ton}} \times \frac{365\ \text{days}}{\text{yr}} \times \frac{\text{ft}^3}{75\ \text{lb}} \times \frac{\text{yd}^3}{27\ \text{ft}^3} \times \frac{3\ \text{ft/yd}}{15\ \text{ft}}$$

$$\times \frac{1\ \text{acre}}{4{,}840\ \text{yd}^2} \times \frac{1}{0.75} = 0.24$$

Stream 2:

$$\text{Acres/yr} = \frac{1\ \text{kkg}}{\text{day}} \times \frac{1\ \text{ton}}{0.91\ \text{kkg}} \times \frac{2{,}000\ \text{lb}}{\text{ton}} \times \frac{365\ \text{days}}{\text{yr}} \times \frac{\text{ft}^3}{90\ \text{lb}} \times \frac{\text{yd}^3}{27\ \text{ft}^3} \times \frac{3\ \text{ft/yd}}{15\ \text{ft}}$$

$$\times \frac{1\ \text{acre}}{4{,}840\ \text{yd}^2} \times \frac{1}{0.75} = 0.02$$

Total acres/yr = 0.24 + 0.02 = 0.26

Total acres required/20 yr = 0.26 x 1.5 x 20 = 7.8

$$\text{Daily Landfill Load} = 12\ \text{kkg/day} \times \frac{365\ \text{days}}{260\ \text{days}} = 16.8\ \text{kkg/day}$$

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*The sludge is thickened to a solid content of approximately 40% prior to landfilling.

Capital Costs

Total Land Cost	7.8 acres x $5,000/acre =	$39,000
Site Preparation Cost	7.8 acres x $1,210/acre =	9,440
Total Land Associated Costs		$48,440
Building Cost		
Trailer w/toilet facility		$ 6,000
Drainage field for septic tank		2,500
Installation of electric lines and telephone service		250
Total		$ 8,750
Equipment Requirements and Costs*		
1 loader		$31,500
1 "dozer"		31,500
1 dump truck (10 ton)		18,200
Thickener (installed)		12,450
Total		$93,650
Capital Cost	$48,440 + $8,750 + $93,650 =	$150,840
Contingency @ 20% capital cost	(excluding land associated costs)	20,480
Total		$171,320

Assumptions and Design Bases for Operating Cost Calculations

Labor:
- 1 loader operator full time
- 1 "dozer" operator full time
- 1 dump truck operator one-half time

Total Labor = 2½ operators

Energy Requirements:
- "Dozer" 30 gal fuel/day
- Truck: 40 gal fuel/day (4 trips/day @ 10 gal/trip)
- Loader: 40 gal fuel/day (4 trips/day @ 10 gal/trip)
- Fuel cost (diesel fuel) = 55¢ gal
- Building utilities: $100/mo

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* Source of landfill moving equipment costs: Report SW-65ts, USEPA, Washington, D.C., 1972. Source of thickener cost: Contractor cost curve and chemical engineering cost index.

Annual Operating Costs

Direct Labor	2½ men x \$9/hr x 8 hr/day x 260 days/yr =	\$46,800
Supervision and Administrative, @ 50% of direct labor	\$46,800 x 0.5 =	23,400
Maintenance @ 4% capital (excluding land associated costs)	\$122,880 x 0.04 =	4,920
Taxes and Insurance @ 4% capital cost	\$171,320 x 0.04 =	6,850
O & M Cost (excluding energy)		\$81,970
Fuel	110 gal/day x 260 days/yr x \$0.55/gal =	\$15,730
Power	\$100/mo x 12 mo/yr =	1,200
Capital Recovery (10 yrs @ 10%) (excluding land associated costs)	\$122,880 x 0.1627 =	19,990
Total Annual Operating Costs		\$118,890

Unit Costs

Cost/kkg of product	$\frac{\$118,890/\text{yr}}{250\ \text{kkg/day} \times 365\ \text{days/yr}} =$	\$1.30
Cost/kkg of waste (dry basis)	$\frac{\$118,890/\text{yr}}{4.75\ \text{kkg/day} \times 365\ \text{days/yr}} =$	\$68.6
Cost/kkg of waste (wet basis)	$\frac{\$118,890/\text{yr}}{19.5\ \text{kkg/day} \times 365\ \text{days/yr}} =$	\$16.7

2.0 COMPANY OWNED AND OPERATED CHEMICAL LANDFILL

Calculations performed for waste streams 1 and 2:

Assumptions and Design Bases for Capital Cost Calculations - Same as for Sanitary Landfill Calculations, except for:

Site Preparation Cost: \$0.56/sq yd, \$2,710/acre
Cost of Synthetic Hypalon Liner: \$0.63/sq ft
Cost of Liner Installation: \$0.013/sq ft
Liner Shrinkage and Anchoring Factor: 5 percent of liner area need
Cost of Liner Cover (1 ft. deep earth dumping and spreading): \$0.033/sq ft
Cost of Final Clay Cover Installation: \$7,475/acre
Cost of Leachate Collection and Monitoring System (installed): 15 percent of landfill cost

Liner Requirements

Area to be lined, 0.26 acres/yr x 20 yr = 5.2 acres
Liner requirements for trench (bottom and cover),
5.2 acres x 43,560 sq ft/acre x 2 = 453,020 sq ft
Liner requirements for trench sides (assume square shape)
$\sqrt{5.2 \text{ acres} \times 43{,}560 \text{ sq ft/acre}}$ x 15 ft x 4 = 28,560 sq ft

Total Liner Requirement (453,020 + 28,560) 1.05 = 505,660 sq ft

Capital Cost

Total Land Cost	7.8 x $5,000/acre =	$39,000
Site Preparation Cost	7.8 x $2,710/acre =	21,140
Hypalon Liner Cost	505,650 sq ft x $0.63/sq ft =	318,560
Cost of Liner Installation	505,650 sq ft x $0.013/sq ft =	6,570
Cost of Hypalon Liner Cover (1 ft. deep earth dumping and spreading)	226,510 sq ft x $0.033/sq ft =	7,475
Cost of Final Clay Cover Installation,	5.2 acres x $7,500/acre =	39,000
Total Installed Land and Liner Costs		$431,745
Cost of Leachate Collection and Monitoring System	$431,745 x 0.15 =	64,760
Building Cost (same as 1.0)		8,750
Equipment Cost (same as 1.0)		93,650
Total Capital Cost (excluding contingency)		$598,905
Total Equipment, Building and Material Cost (excluding Land Associated Costs)		538,765
Contingency @ 20%	$538,765 x 0.20 =	107,755
Total Capital Cost	$598,905 + $107,755 =	$706,660

Assumptions and Design Bases for Operating Cost Calculation - Same as for Sanitary Landfill given in Section 1.0.

Annual Operating Costs

Direct Labor (same as given in Section 1.0)		$ 46,800
Supervision and Administrative @ 50% of direct labor		23,400
Maintenance @4% capital (excluding land associated costs)	$538,765 x 0.04 =	21,550
Taxes and Insurance @ 4% capital cost	$706,660 x 0.04 =	28,265
O&M Cost (excluding energy)		$120,015

Fuel (same as given in Section 1.0)		$ 15,730
Power (same as given in Section 1.0)		1,200
Capital Recovery (10 yrs @ 10%) (excluding Land Associated Costs)	$646,520 x 0.1627 =	105,190
Total Operating Costs		$242,135

Unit Costs

Cost/kkg of product $\frac{\$242,135}{250 \text{ kkg/day} \times 365 \text{ days/yr}} = \$2.65$

Cost/kkg of waste (dry basis) $\frac{\$242,135}{4.75 \text{ kkg/day} \times 365 \text{ days/yr}} = \$140$

Cost/kkg of waste (wet basis) $\frac{\$242,135}{19.5 \text{ kkg/day} \times 365 \text{ days/yr}} = \$34$

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